DEVELOPMENT OF AUTOMATED TEST ANALYSIS, METHODOLOGY AND PROCEDURE FOR INTEROPERABILITY MEASURE IN ISO 18000-7 ACTIVE RFID

by

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In today's modern development process, for all embedded systems including wireless devices, commercial off the shelf products form the basic building blocks of the design. Such projects, often confront interoperability conflicts mainly because of the incompatible assumptions made by the development engineers and many possible solutions available for every problem. Lack of standard procedures and a sound mathematical basis describing the interoperability verification process and electronic tools to aid the interoperability analysis is hindering development of interoperable systems. It is therefore essential to develop a methodology to analyze and develop an interoperable measure of the system during and after development. It is also important to develop tools that will aid interoperability analysis with minimum human supervision.

As an example, active RFID systems conforming to standards such as ISO 18000-7 are designed to meet customer requirements. Apart from conforming to all the required standards, these RFID systems also need to be interoperable with each other. In simple terms the reader of any one vendor should be able to communicate with tags from all vendors.

The first step in verifying interoperability is to determine all factors, including those not explicitly defined by the standard, and determining the extreme limits of operation of each factor. In designing the analysis tool, statistical concepts like analysis of variance will be used to determine the effect of one factor on other and to determine the minimum number of required factors in an experiment. Depending on controllable factors, uncontrollable factors and dependent factors, the minimum number of experiments will be designed using blocking and randomizing techniques. The confidence level associated each experiment will be calculated

using the acceptance sampling technique. Finally a technique to compare experiments performed on the same or different setup is proposed.

This method is not only limited to active RFID but has the potential to revolutionize interoperability verification process among all wireless devices communicating via a command – reply protocol. The developed procedures will assist in planning the development process and also help alter it where and when necessary while not only obeying the standard but also understanding the ultimate essence of it.

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1.0 INTRODUCTION TO INTEROPERABILITY

In today's modern development process, for all embedded systems including wireless devices, commercial off the shelf products form the basic building blocks of the design. Such projects that utilize multiple commercial off the shelf products, often confront interoperability conflicts mainly because of the incompatible assumptions made by the development engineers and the pool of possible solutions available for every problem arising in the way of development.

Figure 1-1: A Communication Chain in Wireless Devices (Portraying choices at every stage)

Consider a wireless system with two or more devices communicating with each other. Interoperability is defined as the property of that system in accepting devices from all possible sources to complete the wireless system (chain[1]) and exchange information using the same communication protocol.

Though acquiring information to develop an interoperable product is crucial, it is a very time intensive process which causes the development teams to typically ignore it. Lack of standard procedures, a sound mathematical basis describing the interoperability verification process and electronic/software tools to aid the interoperability analysis are hindering development of interoperable systems [1].

In an attempt to achieve interoperability among similar wireless products from different manufacturers, standards organizations draft standards with the help of experts in their respective fields. A few world renowned international standards organizations are International Organization for Standards (ISO), International Electrotechnical Commission (IEC) and International Telecommunications Union (ITU). These organizations have existed for more than 50 years and were founded in 1947, 1906, and 1865 respectively. The sole purpose of these organizations and the standards developed, keeping in consideration the requirements of the consumer, is to prescribe a set of rules, or specifications in technical terms, so that different vendors can develop and sell the same product thus eliminating a monopoly to cultivate economic competition and initiate a quest for further development.

Products designed to a standard are said to conform to that particular standard, and testing a product for conformance is called conformance testing. Standards are developed with a notion that if two devices conform to a standard, then they are interoperable. But often this is not the case, especially when the standard is young and in its early stages of development. Here the conformance test alone will not ensure interoperability. It is when the standard fails, a new methodology is required that will help the standard accomplish its purpose and perhaps some day becomes integrated into the standard itself.

[1]Chain = series of communication devices connected one after other by space as a communication channel

It is therefore essential to develop a methodology to analyze and develop an interoperable measure of the system, during and after development. This methodology should include identifying different factors influencing interoperability, analyzing the effect of each factor on interoperability and finally understanding the operation region each factor should support. It is also important to develop tools that will aid the analysis of interoperability with minimum human supervision. The tools should provide simple answers while providing the ability to elaborate upon request [2].

2.0 INTRODUCTION TO RFID

Radio Frequency Identification (RFID) is an example of the latest in wireless technology. An RFID system consists of a Tag and Reader. The Tag in analogous to a bar-code sticker, and the Reader is analogous to the laser bar-code scanner. The biggest advantage of RFID over bar-code is that it overcomes the line of sight barrier and the data on the tag which can be written to up to 1000 times is programmable.

At the very simplest level, Radio Frequency Identification (RFID) technologies allow the transmission of a unique serial number wirelessly, using radio waves. The two fundamental parts of the system that are needed to do this are the RFID tag and the RFID reader. Attaching an RFID tag to a physical object allows the object to be “seen” and monitored by existing computer networks and office administration systems.

RFID can be broadly classified into Active RFID (tag contains a battery) and Passive RFID (tag is powered through energy harvesting technology). Passive RFID is typically used for item management applications and Active RFID has more specific applications like cargo tracking, military applications and sensors.

The majority of the data transfer in an RFID system is between the reader and the tag. It is beneficial to understand a little more about the reader and the tag before defining interoperability in an Active RFID system.

2.1 ACTIVE RFID TAG

The RFID Tag is the device that is attached or “tags” along with the item, to enable efficient tracking of the item through currently installed and applied networks.

An Active RFID tag can be divided into the following components:

1. Antenna
2. Power Circuit
3. Modulator and Demodulator (Transceiver)
4. Processor
5. Switching Circuit
6. Memory
7. Sensors

The components mentioned above are enclosed in a compact casing. The antenna is for receiving and transmitting Radio Frequency (RF) signals. Typically, active tags operate in the UHF frequency (433 MHz). The antenna is designed so that it can receive and transmit in all directions (Omni-directional antenna). The Active Tags are battery powered. The life of the battery depends upon the data transfer between the tag and reader. But for a typical use, the life of the battery is as long as 10-15 years. The demodulator as the name suggests, demodulates the wireless RF data from the reader into baseband. The processor is usually a micro controller that decodes data from the reader (converted into baseband), interfaces with the internal memory and finalizes the response data. The state-machine implementation of the functions of the microcontroller though trivial in theory, can be implemented in innumerable ways. Interoperability testing in this layer is beyond the physical layer interoperability test that is the area of concentration in this research document. The response data is modulated and transmitted through the antenna by the modulation circuit. The switching circuit is one of the most important circuits in the active tag. It is this circuit that controls the power consumption of the tag. The switching circuit waits for the appropriate trigger (command) from the reader before completely turning on the tag, thus saving precious power until it is absolutely needed. The tag can also be equipped with many sensory (pressure, temperature, humidity, speed etc.). The tag can be requested to transmit data from any of the sensors making it possible not only to identify the item but also the condition of the item and the environment history.

Figure 2-1: Echo Point Active Tag

It is important to note that the active tag protocol does not allow the tag to start communication between the tag and the reader or the tag and any other tag. Only the active reader can initiate communication.

2.2 ACTIVE RFID READER

The reader is a handheld or fixed unit that can interrogate (hence the other name interrogator) nearby RFID tags and obtain their ID numbers using radio frequency (RF) communication. These ID numbers are unique to each tag.

An Active RFID Reader can be divided into the following components:

1. Antenna
2. Power Circuit
3. Modulator and Demodulator (Transceiver)
4. Processor
5. Memory
6. Host Interface

Figure 2-2: Echo Point Fixed Active Reader

Similar to the RFID Tag, the RFID Reader also has an omni-directional antenna that allows it to broadcast commands in all direction to find tags and initiate communication. Active readers are generally powered through the AC power supply and rarely have issues with availability of power. The modulator circuit modulates the data that are to be transmitted to the tag as designated by the processor. The demodulator converts the RF signals to baseband which are processed by the processor, which is usually a micro controller. Again the state-machine implementation of the micro controller will depend upon individual preferences, interpretation of the standard and specification document as drafted. There may or may not be memory on the active reader. Active readers have an interface circuitry with the host, usually a personal computer. The interface can be through different protocols like Ethernet, USB or RS232. The host interface protocol has not yet been standardized. This makes the design of an automated interoperability test for a reader more challenging.

3.0 INTEROPERABILITY IN ACTIVE RFID

Interoperability in RFID is similar to any other wireless system or chain of wireless systems. The reader initiates data transfer. If the intended tag receives the correct initiative from the reader it responds with the data requested back to the reader.

Interoperability in an Active RFID system implies the ability of the system to replace any of the reader or the tags with commercially available equipment designed for the same protocol and still complete the data chain mentioned above. In simple terms the reader of any one vendor should be able to communicate with tags from all vendors [3], [4].

Figure 3-1: Interoperability Illustrated

Initial analysis of different RFID systems has proven that conformance testing alone is not sufficient to verify the necessary level of interoperability. Satisfying conformance is only the necessary condition for interoperability but not the sufficient condition for interoperability. There are many factors not explicitly defined by the standard that hinder interoperability. Misinterpretation and inability to predict other's interpretations are major roadblock for developing interoperable RFID systems. Hence there is a requirement for an "Interoperability Test" that will verify interoperability.

4.0 UNDERSTANDING THE PROBLEM

A problem with interoperability in active RFID is identified if a reader is not able to read (the technical term being collect) active tag information from a different manufacturer. The first suspect is the conformance property of the tag and also the reader. Upon investigation an alarming truth was discovered that the problem with interoperability was not because of conformance issues, but because of different interpretations of the protocol described in the standard and implementing the tag to function for that interpretation only. Neither the tag nor the reader was at fault in creating this problem for interoperability since no one violated the standard per se. This led to a new thought that there are factors within the standard that will create problems with interoperability which have to be researched and solved.

In this section, an example will be explained to prove that there might be two RFID systems that completely conform to the standard but still will not be interoperable with each other.

4.1 BACKGROUND OF THE PROBLEM

Figure 4-1 depicts the wakeup signal and the co-header signal as per ISO 18000-7.3 standard for active RFID devices. According to the ISO 18000-7.3 standard, the length of the wakeup can be between 2.4 seconds to 4.8 seconds. The wakeup should be followed by the co-header signal. The length of the co-header signal is 100ms. The standard currently does not define a fixed time difference between wakeup and co-header signal. The only restriction is that the time difference between start of wakeup to the end of co-header should be less than or equal to 4.9 seconds [5].

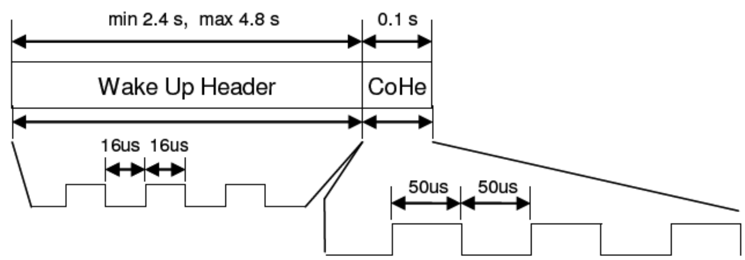

Figure 4-1: Wakeup Signal and Co-Header Signal Description

If vendor A is transmitting the co-header signal 200us after transmission of the wakeup signal, it is considered to be within the standard. Similarly if vendor B is transmitting co-header immediately after the transmission of the wakeup signal without any delay, it is still considered to be within the standard. But the problem encountered here is that vendor A is not able to wakeup vendor B tags. It is because vendor B tags require the reader to transmit the wakeup and the co-header signal without any delay. It is problems like this which hinder interoperability. The proposed interoperability analysis will be helpful to identify such factors, though considered insignificant, strongly influencing interoperability and the future scope of the active RFID market.

4.2 TRADITIONAL APPROACH – LIMITATIONS

Consider two different RFID systems – RFID System A and RFID system B. The simplest procedure to test for interoperability among RFID system A and RFID system B is to send every possible command from Reader A to Tag B and from Reader B to Tag A. If for every command the response is as expected, then the two RFID systems are interoperable. This method can be considered a trial and error method or traditional method.

The drawback of this procedure is that the time to test increases significantly with addition of each new RFID system into the test scenario.

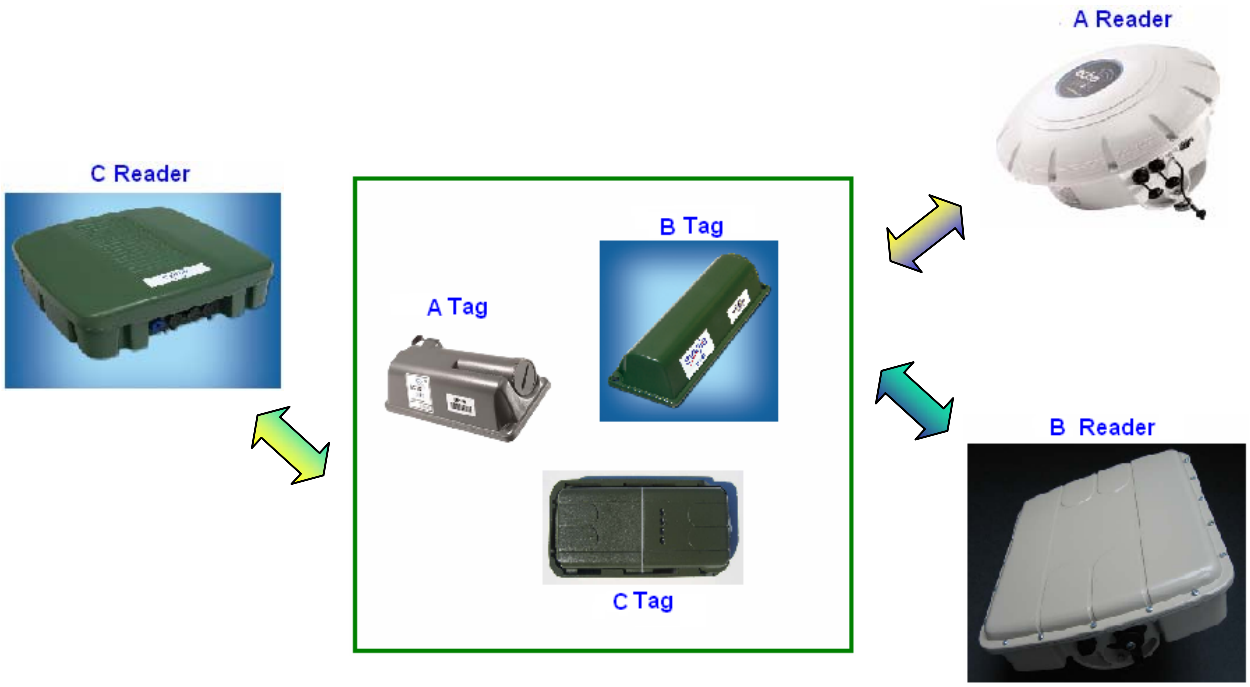

Figure 4-2: Traditional Approach to Interoperability Testing (3 Systems)

A major shortcoming of the traditional approach is also that the test engineer may not have access to all RFID systems in their latest versions to test for interoperability. Even after testing for interoperability with all RFID systems available, it is still unclear, the status of interoperability with inclusion of a new RFID system at a later date.

If two RFID systems are not interoperable, it is not possible by this method to determine which RFID system is at fault and proceed for further investigation to solve the problem.

In addition, for each equipment model variant (input factor), a full regression set of tests must be performed or a verbal argument must be made as to why retesting is unnecessary. Such a situation is problematic.

Therefore it is essential to test the interoperability RFID system with a reference system this will ascertain and predict the interoperability status

4.3 STATEMENT OF THE PROBLEM AND SOLUTION

Because the traditional trial and error method fails to answer the questions as to why two RFID systems are not interoperable, a more in-depth analysis and testing of the system is necessary. From the example in section 4.1, it can be understood that designing the tag to function at only the typical value described in the standard is the main reason for two RFID systems not being interoperable.

Therefore a more deliberate approach is to comb through the standard and document all the potential factors that can cause issues with interoperability. Next the tag should be tested to work as expected for not only the typical value mentioned in the standard but also in the entire range of permitted values of each potential factor.

For determining that a particular RFID system functions as expected at the extreme limits of operation defined by the ISO 18000-7 standard and at the intermediate values bounded by the extreme limits [6], an automated experiment (or a set of automated experiments) will be developed. This experiment will include a series of tests in which purposeful changes (within extreme limits of operation defined by the ISO 18000-7 standard, including the extreme limits) are made to the input variables so that the changes in the outputs may be observed. This experiment should be a robust process meaning that this process should be minimally affected by external sources of variability.

In designing this experiment, statistical concepts like analysis of variance [Definition of analysis of variance in Section 6.1] will be used to determine the affect of one factor on other (separating dependent and independent factors) and to determine the minimum number of required factors in an experiment. Depending on controllable factors, uncontrollable factors and dependent factors, the minimum number of experiments will be designed using blocking and randomizing techniques. Each experiment will be performed with a Confidence Level [Association with Confidence Level is explained in Section 6.5] to determine if all factors influencing interoperability work as expected at the entire range of values defined by the ISO 18000-7 standard without testing at every possible value. Since the input to certain factors can lie between two numbers on the rational number line, there are infinite possible values for that input which in practice cannot be tested. The Quality Level of all experiments will be combined if possible to determine the total Confidence Level of the test determining interoperability. Finally depending upon the result of each individual experiment, a statement will be made upon the interoperability/non-interoperability of an RFID system where each factor is tested with a particular Confidence Level.

To realize the interoperability test as mentioned, the input to the tag should be transmitted from a common source which is transparent (in design and application) and impartial. Transmitting custom commands from this source, it is possible to verify if the tag under test functions as expected or to determine values for each factor within the standard, where the tag fails to respond.

4.4 GOALS OF THE RESEARCH

- Research the ISO 18000-7 standard and commercial active RFID tags and readers to determine all the factors that affect the interoperability property of the system.
- Separate dependent and independent factors providing an alternative to a full regression analysis significantly decreasing the time required for test.
- Program a commercial RF signal generator to emulate a conforming active RFID reader (also called GOLD Standard Reader).
- Research the selected RF signal generator to determine the resolution of different factors.
- Develop a mathematical technique to test factors at some values and extend the results to the entire range of values associated with a confidence level.
- Incorporate the results of conformance tests to make the interoperability test efficient and effective.
- Design an experiment to prove the practicality of the Interoperability test methodology in active RFID.
- Test commercial active RFID tags using the test setup and document results.

5.0 RF & COMMUNICATIONS TERMINOLOGY

5.1 MODULATION

Modulation in simplest terms is the process of modifying a periodic waveform in accordance with the message signal.

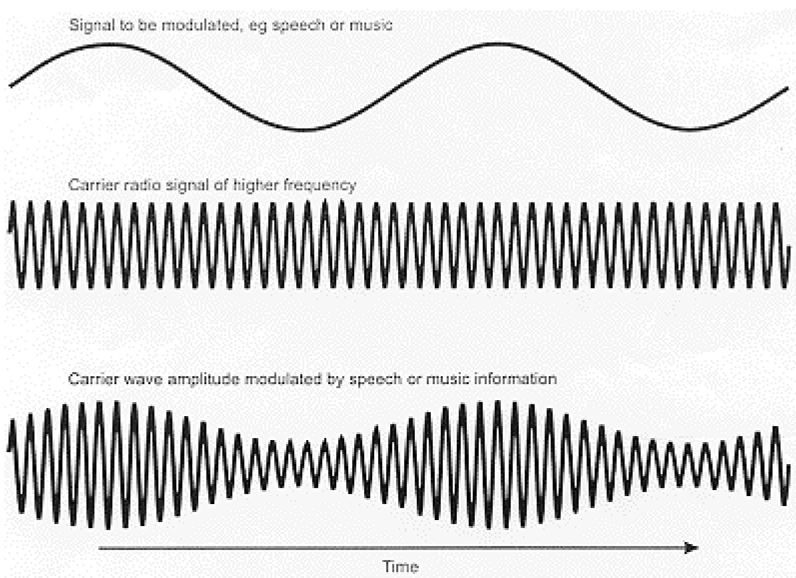

Figure 5-1: Principle of Modulation

Normally a high-frequency sinusoid waveform is used as a carrier signal. A high frequency sinusoidal waveform has three key parameters – amplitude, frequency and phase. All the parameters can be modified according to the message signal to generate the modulated waveform. A device that performs modulation is termed a modulator.

The aim of modulation is to convert a baseband or message signal into a high frequency signal containing information to be transmitted. This has several advantages the most important being signals becoming more immune to noise. Modulation is the soul of modern communication systems. Modulation can be further divided into Analog modulation and Digital modulation schemes.

5.1.1 Analog Modulation

In analog modulation the message signal is an analog-continuous signal. The modulation is applied continuously in response to the analog information signal.

Common analog modulation techniques are:

- Angular modulation
  - Phase modulation (PM)
  - Frequency modulation (FM)

- Amplitude modulation (AM)
  - Double-sideband modulation with unsuppressed carrier (used on the radio AM band)
  - Double-sideband suppressed-carrier transmission (DSB-SC)
  - Double-sideband reduced carrier transmission (DSB-RC)
  - Single-sideband modulation (SSB, or SSB-AM), very similar to single-sideband suppressed carrier modulation (SSB-SC)
  - Vestigial-sideband modulation (VSB, or VSB-AM)
  - Quadrature amplitude modulation (QAM)

5.1.2 Digital Modulation

In digital modulation the continuous message signal is converted or encoded into a digital signal (typically 2 amplitude values). An analog carrier signal is modulated by a digital bit stream of either equal length signals or varying length signals. A simple way of visualizing digital modulation is when we have two carriers, each representing bit '1' and bit '0' respectively. The two carriers may be different in any of the three key aspects of a carrier signal.

The three most common digital modulation techniques are:

1. Frequency Shift Keying
2. Amplitude Shift Keying
3. Phase Shift Keying

Most of the wireless devices use modulation that can be grouped into one of the above three techniques.

5.2 DE-MODULATION

De-modulation is the exact opposite of modulation. Here the carrier signal is removed and the original baseband, i.e., the message signal is retrieved. Demodulating is necessary because the receiver system receives a modulated signal with specific characteristics, and it needs to turn it into base-band.

There are several methods of demodulating depending on what parameters of the base-band signal are transmitted in the carrier signal, such as amplitude, frequency or phase. But one must normally know in advance what type of modulation has been performed on the carrier to perform demodulation.

5.3 CARRIER FREQUENCY & MESSAGE SIGNAL

The frequency of the un-modulated electrical wave at the output of an amplitude modulated (AM), frequency modulated (FM), or phase modulated (PM) transmitter is the system's carrier frequency. This can also be viewed as the output of the modulator when modulation is zero. A carrier signal's frequency is generally very high when compared to the message signal.

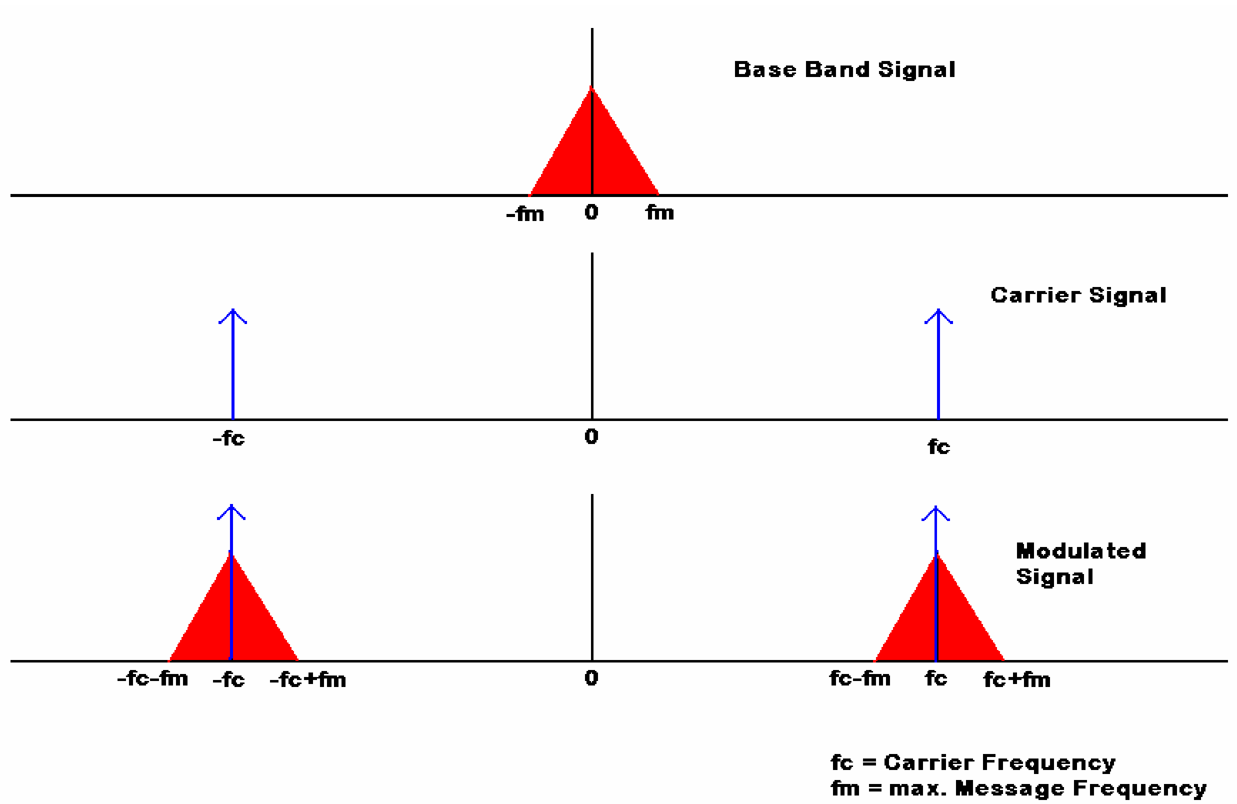

Figure 5-2: Frequency Translation as a result of Modulation

Message signal, as the name suggests, is a very low frequency signal which actually contains the data. Hence the name base band signals. But as most of the messages are low frequency signals, they cannot be communicated through free space without modulation.

Modulation can be viewed as the process of converting a low frequency signal whose frequency spectrum is centered on zero, to a high frequency signal whose center is at the carrier frequency.

It is interesting to note that the modulated signal will occupy the same bandwidth as occupied by the un-modulated baseband signal.

5.4 NOISE

In communication, noise refers to influences on the modulated carrier signal that affect the recovery of the message signal. In simpler words, what we receive that is useless is noise. Noise is what drives communication to be more efficient.

Noise can affect any of the three key parameters of the carrier. It is interesting to note that when one type of modulation is employed and noise affects another parameter, the message is not altered. This is this reason that many types of modulation were developed.

Sometimes the same message is modulated in different ways and sent from one place to another. The reason being, it is highly improbable that the same noise can affect the same signal in such a way that when demodulated, the effect will alter the message in the same place. This is called modulation diversity transmission.

5.5 SIGNAL TO NOISE RATIO (SNR)

Signal-to-noise ratio (abbreviated SNR) is an electrical engineering concept defined as the ratio of a signal power to the noise power corrupting the signal.

$$SNR = \frac{P_{Signal}}{P_{Noise}} = \left(\frac{A_{Signal}}{A_{Noise}} \right)^2$$

In less technical terms, signal-to-noise ratio compares the level of a desired signal (message) to the level of unwanted noise. The higher the ratio, the more clear the message is and the better is the communication system. One should note that SNR is not the only thing that rates a communication system. SNR is usually expressed in dB using the formula:

$$SNR(dB) = 10\log_{10}\left(\frac{P_{Signal}}{P_{Noise}} \right) = 20\log_{10}\left(\frac{A_{Signal}}{A_{Noise}} \right)$$

If reference (denominator) power or amplitudes are expressed in "milli" then SNR is said to be expressed in dBm.

5.6 CARRIER TO NOISE RATIO

Carrier to noise ratio is very similar to SNR. The carrier-to-noise ratio (CNR) is a measure of the received carrier strength relative to the strength of the received noise.

High CNR provides better quality of reception, and generally results in higher communications accuracy and reliability. Engineers specify the CNR in decibels (dB) between the power in the carrier of the desired signal and the total received noise power. If the incoming carrier strength in microwatts is $P_{carrier}$ and the noise level, also in microwatts, is P_{noise}, then the carrier-to-noise ratio in dB is given by the formula:

$$CNR(dB) = 10\log_{10}\left(\frac{P_{Carrier}}{P_{Noise}} \right)$$

The SNR specification is more meaningful in practical situations. The CNR is commonly used in satellite communications systems to point or align the receiving antenna. The best alignment is indicated by the maximum CNR.

5.7 SYMBOL RATE

In digital communications, the symbol rate is the bit rate (bits per unit time) divided by the number of bits transmitted in each symbol. Symbol rate is measured in symbols per second, hertz (Hz), or baud. The term baud rate is synonymous with symbol rate.

There is no fixed relationship between the symbol rate and the bit rate. The simplest digital communication links typically have a symbol rate equal to the bit rate.

5.8 FREQUENCY SHIFT KEYING

Frequency Shift Keying (FSK) is a type of digital modulation. Here the message signal, which is digital, shifts or modulates the carrier signal frequency between two predefined values, each one corresponding to *symbol high* or *symbol low* respectively.

The carrier frequency is shifted between two discrete values termed the mark frequency and the space frequency. Usually mark frequency is greater than space frequency and represents bit ‘1’. Figure 5-3 illustrates a FSK modulated signal.

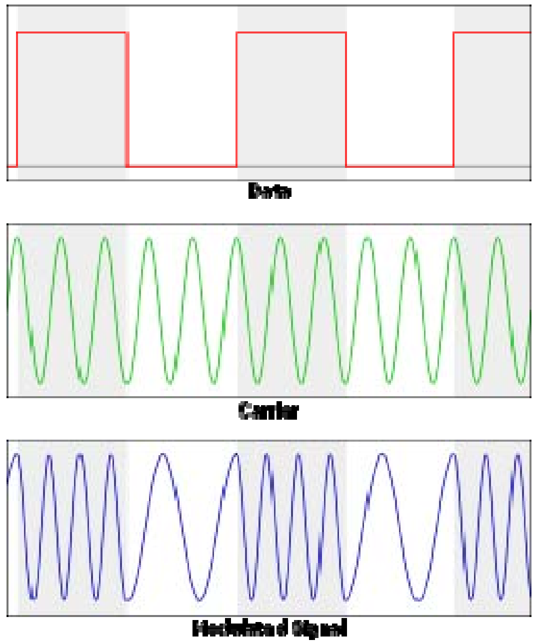

Figure 5-3: FSK Modulation. Courtesy: Wikipedia

5.9 FREQUENCY DEVIATION

Frequency deviation quantifies the amount by which a frequency differs from its specified value, as when measuring how much an oscillator frequency deviates from its nominal frequency.

In frequency modulation, frequency deviation refers to the maximum absolute difference, during a specified period, between the instantaneous frequency of the modulated wave and the carrier frequency.

In other words, it is the difference between mark frequency and carrier frequency or carrier frequency and space frequency.

5.10 AMPLITUDE SHIFT KEYING

In amplitude shift keying (ASK) modulation the amplitude of an analog carrier signal varies in accordance with the bit stream (message signal), keeping frequency and phase constant. The level of amplitude can be used to represent binary logic ‘0’ and ‘1’. We can think of a carrier signal as an ON or OFF switch. In the modulated signal, bit ‘0’ is represented by the absence of a carrier, thus giving OFF-ON keying operation and hence the name. Figure 5-4 shows ASK modulated signal.

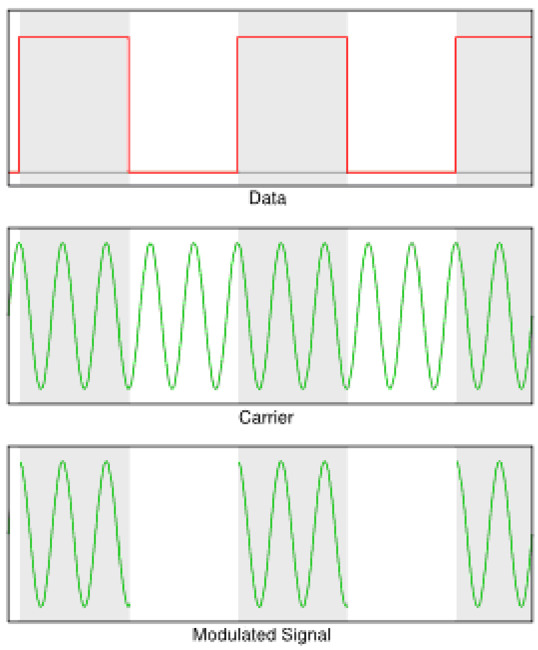

Figure 5-4: ASK Modulation

5.11 PHASE SHIFT KEYING

PSK is similar to FSK, the only difference is that the phase changes where the frequency would otherwise change. In FSK the message signal, which is digital, shifts the carrier signal phase between two predefined values, each one corresponding to bit ‘1’ and bit ‘0’ respectively.

Generally the two phases are 180 degrees apart. The frequency of the carrier remains the same. Figure 5-5 illustrates a PSK modulated signal.

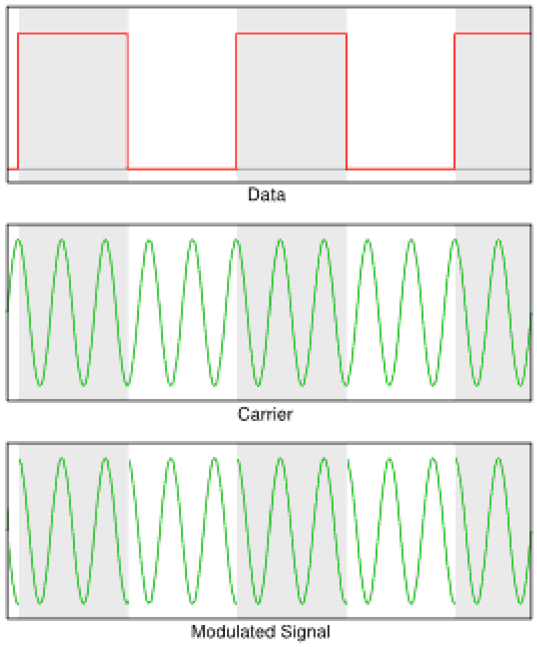

Figure 5-5: PSK Modulation

5.12 PULSE WIDTH

Pulse width is defined as the difference between the consecutive times when the signal crosses zero or some predetermined level.

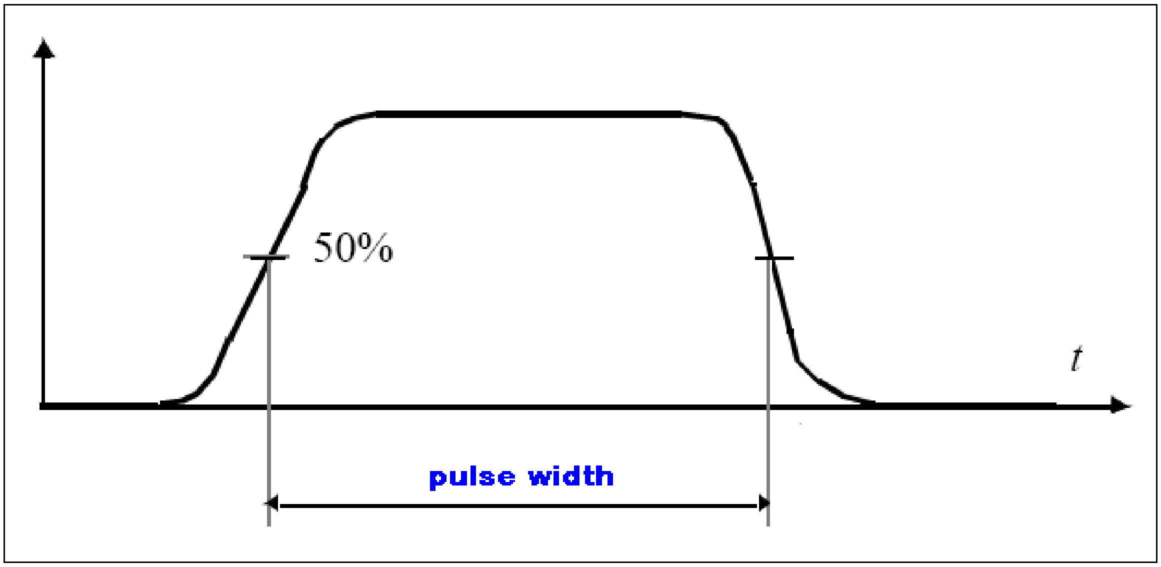

Figure 5-6: Pulse Width

5.13 RISE TIME AND FALL TIME

Rise time (t_r) is typically defined as the time required by the rising edge of the pulse to go from 10% of maximum value to 90% of maximum value.

Fall time (t_f) is typically defined as the time required by the falling edge of the pulse to go from 90% of maximum value to 10% of maximum value.

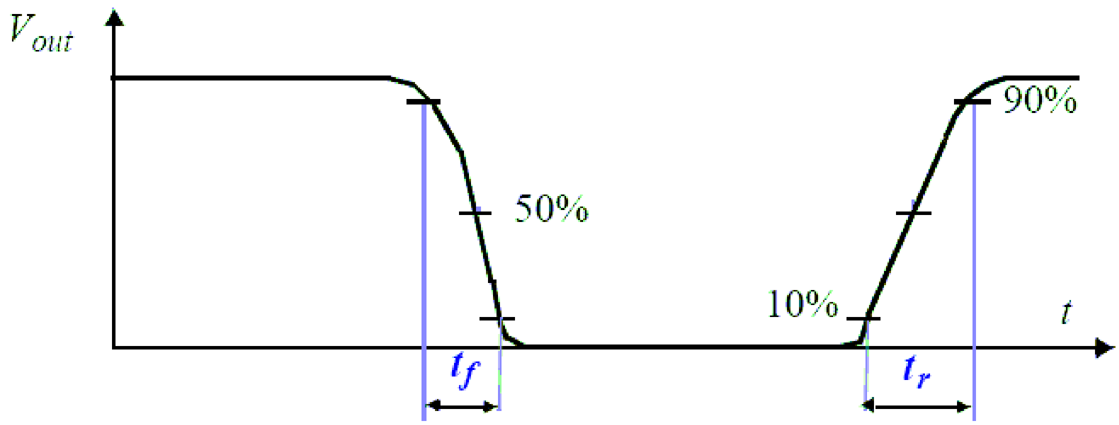

Figure 5-7: Rise time and Fall time

5.14 BANDWIDTH

A wireless device receives maximum power at f_c and receives half the power at f1 and f2, where f1<f2. Then the bandwidth is defined as the difference between the half power frequencies (f2-f1). This is also called the 3dB bandwidth.

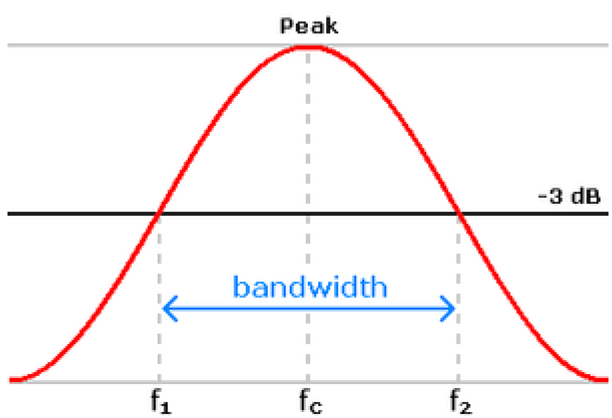

Figure 5-8: Bandwidth. Courtesy: Wikipedia

5.15 RFSG

A Radio Frequency Signal Generator (RFSG) is a wireless devise that can transmit modulated RF signals at a particular frequency. The type of modulation, the message signal, the carrier frequency and the power of transmission are all user programmable.

Many industry standard signal generators are available like NI5671, Rhodes and Schwarz SMJ100A and Keithley 2910. In this research the Rhodes and Schwarz SMJ100A and the ni5671 signal generators are used.

5.16 TRIGGER

Trigger, also known as trigger pulse is an electronic signal that begins (starts) an operation. Devices can be configured to start the operation on the rising edge of the pulse or the falling edge of high pulse depending on configuration options supported by the device.

5.17 RFSA

A Radio Frequency Signal Analyzer (RFSA) is a device which acts like a transducer which converts electro magnetic energy into electrical signals. RFSAs are typically used for data acquisition of radio waves. The frequency input range typically varies from DC to 2.5GHz. There are many RFSAs available in market like the NI5660 and Keithley 2810.

5.18 GOLD REFERENCE SYSTEM

A GOLD Reference System is typically designed using commercial test equipment to be analogous to the original system under test or development. This reference system is used to aid in the designing or the testing process of the original system. The reference system is designed to conformance and to satisfy the specifications rather than being cost effective and production ready.

5.19 STATE MACHINE

A state machine or finite state machine (FSM) is a conceptual model of a system that explains it behavior. It allows creating a visual representation of the theoretical modes of operation of the system also called states of the system. The state is a unique configuration of the system that is stored in the memory of the system.

The state machine vectors and mapping will describe the conditions of change or transfer between pre-configured digital states.

5.20 PRINTED CIRCUIT BOARD

A printed circuit board (abbreviated and widely known as PCB) is a rugged, inexpensive, and highly reliable mechanical support to an electronic circuit. It is used to support connecting electronic components using electronic pathways or traces. The traces are etched from copper sheets laminated onto a non-conductive substrate.

5.21 DATA ENCODING – DECODING

In simple terms, data encoding is the process of compacting data to make data transfer more effective. For example, writing only ‘M’ for male and only ‘F’ for female is encoding data. Encoding data will enable higher data rates and increase security. For example, ‘M’ can be replaced by ‘J’ and ‘F’ can be replaced by ‘Y’.

Data decoding is the process of elaborating the received compacted data or in other words understanding the encoded data. This can only be done if there is a prior understanding between the transmitter and the receiver upon the data encoding-decoding scheme being used. For example, while reading, 'M' is always understood as short for male by the reader.

There are many data encoding-decoding schemes for different applications like security, higher data rates, error detection, error correction and synchronization.

5.21.1 Manchester Encoding – Decoding

This encoding – decoding scheme is used for synchronization between the receiver and the transmitter. In this scheme, there is always a transition per bit time. In other words, each bit is represented by a sequence of 1 and 0 bits. For example data '1' is represented as "01" and data '0' can be represented as "10".

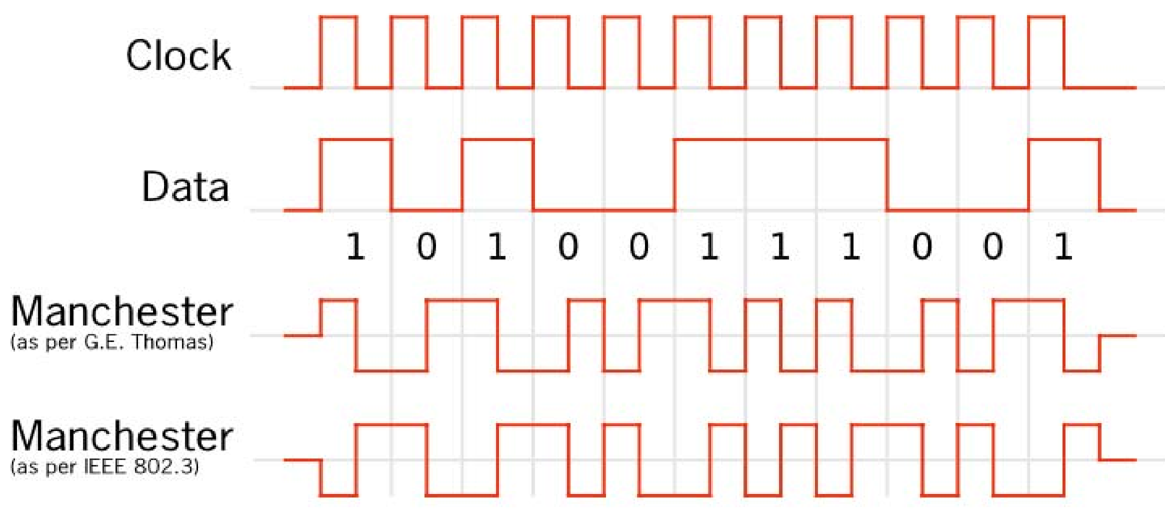

Figure 5-9: Manchester Coding. Courtesy: Wikipedia

There is no DC component in such an encoding technique. It also provides a certain error detection facility as it can be inferred as there is some error in the received data if there is no transition per bit time.

5.22 CRC

Cyclic Redundancy Check (CRC) is an error detection technique employed during data transmission. The CRC technique is a mathematical technique where the data is mathematically processed to calculate a CRC code which is also transmitted along with the data. This will definitely introduce an overhead in data transmission reducing the data rate but it is the price that has to be paid for error detection.

At the receiver, the same pre-agreed mathematical analysis is performed on the received data, and the calculated CRC code is compared with the received CRC code to detect errors.

CRC schemes are popular because they are simple to implement in binary hardware, easy to analyze mathematically, and are particularly good for detecting common errors caused by noise in transmission channels.

5.23 IQ DATA

A sinusoidal wave of the form $f(t) = r.\cos(\omega t + \theta)$, at an instant can be expressed in terms of its in-phase component (I) and Quadrature-phase component (Q). The I and Q components are orthogonal and hence do not interfere with each other.

$I(t) = r \times \cos(\theta) \times \cos(\omega t)$

$Q(t) = r \times \sin(\theta) \times \sin(\omega t)$

F(t) = I(t) – Q(t)

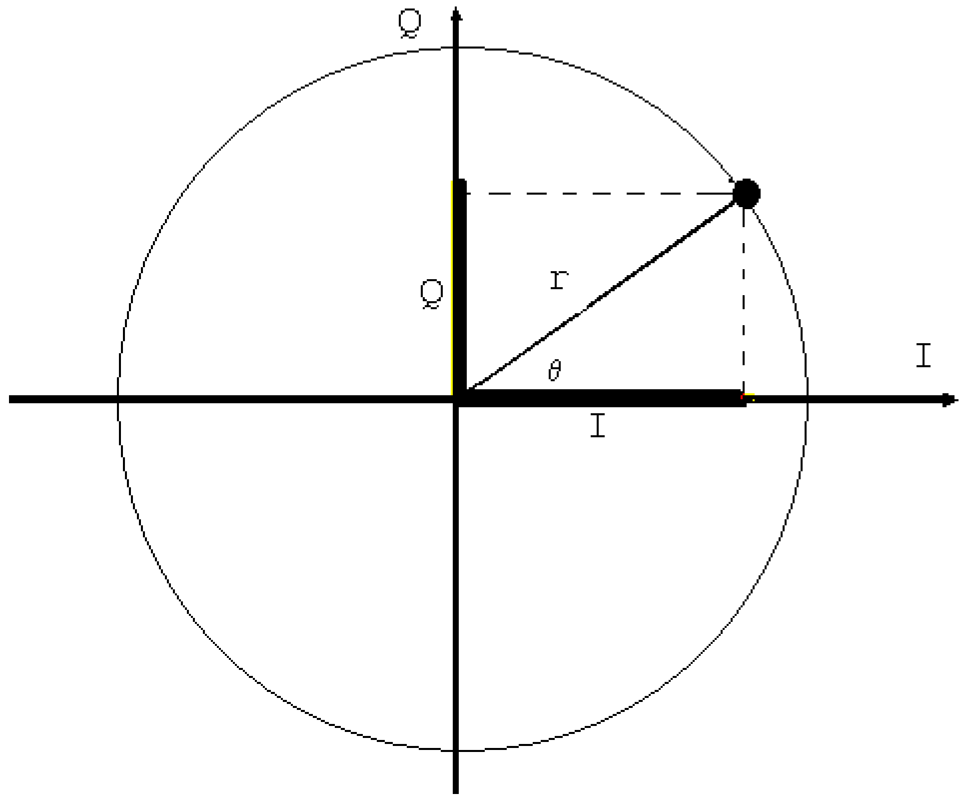

Figure 5-10: IQ data. Courtesy: NI

IQ data are important because most RFSAs give IQ as their output before demodulation. This is fed to the demodulator as input. Similarly the baseband signal after modulation is given as input in IQ data format to RFSGs which generate the waveform at IF.

6.0 STATISTICAL TECHNIQUES

Statistical and mathematical concepts and techniques are often used in testing and quality control experimentation. The mathematical analysis on the experimental results is usually utilized to calculate the mean response of the data thus determining a valid range of acceptable outputs from its standard distribution when there is an error component interleaved with the data of the result. Although in an ideal test scenario there is absolutely no uncertainty about the experimental results, this is not the case in a practical test or experiment. There will be limitations in a real world experiment which will make it necessary to associate a level of confidence to the experimental results which can be achieved using statistical techniques. Statistical analysis is also helpful to determine the effect on the experiment output results of varying the input parameters.

There are two different statistical techniques that are used in the methodology developed to test interoperability in Active RFID.

1. Analysis of Variance
2. Acceptance Sampling

The principles of these two statistical techniques are introduced in this chapter and the procedures are explained in detail along with applications. The specific applications of the statistical techniques in the interoperability test methodology are explained in later chapters.

6.1 ANALYSIS OF VARIANCE

Analysis of variance (ANOVA) is a method used in statistics to evaluate the sources of output variation. It ranks the input variables and the associated cross products based on their contributions to the response variation of a process [7]. In simple terms it is a measure of the affect of variation in input of the system on the output of the system. However, analysis of variance has a much wider application than the explanation above and is probably the most useful technique in the field of statistical inference. For understanding the interoperability test methodology that is proposed in this dissertation, it is sufficient to understand the application of Analysis of Variance in a one-way or single factor model.

In a single factor model of ANOVA the effect of only one input on the output parameter is investigated. A change is purposefully induced in a single input parameter of the design system and the resulting output is recorded. The one-way ANOVA investigation will give us a measure (numerical value) of the change in the output parameter for a change in the input parameter. This numerical value can be compared to a fixed reference value to decide if the change in input has a significant impact on the desired output. The fixed reference values can be obtained from the F-Distribution Tables. The appropriate table can be selected based on the tolerance of error within the data collected (α), and its interpretation and the replication property of the experiment designed for the data collected. The application of the F-Distribution tables is not limited to ANOVA analysis but is typically used as a null distribution of a test statistic especially in likelihood-ratio tests. A likelihood-ratio test is a statistical test for selecting between two hypotheses, based on the value of this ratio. In a single factor ANOVA analysis the two hypotheses being; "The input parameter has a significant affect on the output parameter" and "The input parameter has no significant affect on the output parameter" [8].

6.2 REPRESENTATION OF ANOVA

The ANOVA of a set of data can be represented in two forms: The Means Model and The Effects Model. Both of the models are linear statistical models, that is, the response variable or output is a linear function of the model parameters or inputs (input in case of a one-way ANOVA). For simplicity, only the Effects Model is explained and will be used in the Interoperability Test Methodology.

Consider the data collected in Table 6-1 for ANOVA analysis. The table consists of *a* treatments (or levels) of a single factor. An entry y_{ij} represents the j^{th} observation taken under treatment *i*. Each treatment has *n* observations.

Table 6-1: Data Collection for ANOVA Analysis

Treatment	Observations				Totals	Averages
1	y_{11}	y_{12}	…	y_{1n}	$y_{1.}$	$\overline{y_{1.}}$
2	y_{21}	y_{22}	…	y_{2n}	$y_{2.}$	$\overline{y_{2.}}$
3	y_{31}	y32	…	y_{3n}	$y_{3.}$	$\overline{y_{3.}}$
.	.	.	.	.	.	.
.	.	.	.	.	.	.
.	.	.	.	.	.	.
a	y_{a1}	y_{a2}	…	y_{an}	$y_{a.}$	$\overline{y_{a.}}$

According to the Effects Model, every element can be represented as:

$$y_{ij} = \mu + \tau_i + \in_{ij}$$

where, i = 1, 2, … a and j = 1, 2, … n

In the Effects Model, μ is the overall mean of all the elements in the table and is a common parameter to all the elements in the table. The parameter τ_i is a parameter unique to the i^{th} treatment row and is called the treatment effect for that row. The parameter $\in_{ij}$ is a random error component that incorporates all sources of variability from all sources in the experiment including measurement, influence of uncontrolled factors, change in experimental units and process noise [9].

For hypothesis testing, the model errors are assumed to be normally and independently distributed random variables with a mean of zero. The other condition for the ANOVA analysis to hold is that the observations are all mutually independent.

The Effects Model is further divided into: The Fixed Effects Model and The Random Effects Model. If the *a* different treatments are specifically chosen for the experiment and the results of the analysis cannot be extended to similar treatments that are not explicitly considered, then it is called a Fixed Effects Model. Alternatively, if the *a* treatments are a set of random samples (though equidistantly distributed from the mean) from a large (or infinite) population and the results from this small set of data can be extended to the entire population, it is called a Random Effects Model.

The computational effort, procedure and the ANOVA table for the Random Effects Model are identical to those for a Fixed Effects Model. The Interoperability Methodology that is described in this document follows the Random Effects Model.

6.3 ANOVA ANALYSIS: BASICS

In this section the basic formulas and the procedures to assess the effect of a single input on the output of the system using a one-way ANOVA is described. Consider the data collected in Table 6-1 for ANOVA analysis. In the table $y_{i.}$ is the total of all observation in a treatment, $\overline{y_{i.}}$ is the average of all observations in the treatment, $y_{..}$ is the total of all *N* observations, in all *a* treatments and $\overline{y_{..}}$ is the average of all N observations, in all a treatments. These can be expressed in the following equations:

$$y_i. = \sum_{j=1}^{n} y_{ij}$$

$$y.. = \sum_{i=1}^{a}\sum_{j=1}^{n} yij$$

$$\overline{y_i}. = y_i./n$$

$$\overline{y..} = y../N$$

where, i = 1, 2, …a and N = an

In simple terms, from Table 6-1, to understand if the output responds to changes in the input parameter, the average of each treatment is compared to the average of all observations or the expected result (Every $\overline{y_{i.}}$ is compared to $\overline{y_{..}}$). If the difference between the average of one treatment and the average of all observations or the expected result is significant (significant for the experimenter or user), then it can be concluded that the input has a significant change in the output of the system.

Explaining the concept in technical terms, to analyze the effect of change in the input parameter on the output of the system, an hypothesis is created about all the treatment effects in the experimental data collection.

$$H_0 : \tau_1 = \tau_2 = ... = \tau_a = 0$$
$$H_1 : \tau_i \neq 0 \text{ for at least one } i$$

where, 1 < i < a.

The hypothesis H_0 states that all treatments are identical and the value of the treatment effects of all the treatments is zero. The hypothesis H_1 states that there is at least one treatment that is different from all other as the value of that treatment effect is not zero.

The total corrected sum of squares SS_T is used as a measure of overall variability in the data and through mathematical decomposition and construction[1] can be proved to be the addition of sum of squares due to treatments $SS_{Treatments}$ and the sum of squares due to error SS_{Error}. The parameter $SS_{Treatments}$ is between the *a* treatment levels and the parameter SS_{Error} is within the *n* different observations in the same treatment.

The simplified and commonly used formulae to calculate the sum of squares:

$$SS_T = SS_{Treatments} + SS_{Error}$$

$$SS_T = \sum_{i=1}^{a}\sum_{j=1}^{n} y_{ij} - \frac{y..^2}{N}$$

$$SS_{Treatments} = \frac{1}{n}\sum_{i=1}^{a} y_i.^2 - \frac{y..^2}{N}$$

$$SS_{Error} = SS_T - SS_{Treatments}$$

There are total *N* observations giving the SS_T, *N-1* degrees of freedom (In statistics, the phrase degrees of freedom is used to describe the number of values in the final calculation of a statistic that are free to vary). There are *a* levels of treatments giving the $SS_{Treatments}$, *a-1* degrees of freedom. Finally, each treatment has *n* replicates giving *n-1* degrees of freedom and for all *a* treatments SS_{Error} has *a(n-1)* degrees of freedom.

Degree of Freedom of ' SS_T ' = N-1

Degree of Freedom of ' $SS_{Treatments}$ ' = a-1

Degree of Freedom of ' SS_{Error} ' = a(n-1) = N-a

[1] Expanding Summation and Rearranging terms

The sum of squares of error and the sum of squares of treatments, when divided by their respective degrees of freedom, give their respective mean square values.

$$MS_{Treatments} = \frac{SS_{Treatments}}{a-1}$$

$$MS_{Error} = \frac{SS_{Error}}{N-a}$$

$$F_0 = \frac{MS_{Treatments}}{MS_{Error}}$$

The expected value of MS_{Error} estimates (approximates) the variance of all the observation in all treatments. If there is no difference in treatment means (τ_i), the value of $MS_{Treatments}$ also estimates (approximates) the variance of all the observation in all treatments. If there is a difference in treatment means (τ_i), the value of $MS_{Treatments}$ estimates to a value greater than the variance of all the observation in all treatments. The selection between the two hypothesis H_0 and H_1 can be achieved by comparing MS_{Error} and $MS_{Treatments}$. The hypothesis H_0 should be rejected and H_1 can be accepted when the ratio between $MS_{Treatments}$ and MS_{Error} is greater than the value from the F-Distribution Table with *a-1* and *N-a* degrees of freedom and error α [9].

Reject H_0, i.e., the input parameter will significantly affect the output when,

$$F_0 >> F_{\alpha, a-1, N-a}$$

There are two types of errors that may be committed when testing hypotheses. If H_0 is rejected when it is true, then a *Type I Error* has occurred. If H_0 is not rejected when it is false, then a *Type II Error* has occurred. The probability of a Type I Error happening is α and the probability of a Type II Error happening is β. An experiment is initialized for a specific, practical and reasonable value of α and developed to accommodate a small value for β. More about errors and the operational characteristics of the experiment are explained in the discussion of the Acceptance Sampling technique.

The one-way ANOVA test procedure is summarized in Table 6-2.

Table 6-2: ANOVA Table

Source of Variation	Sum of Squares	Degrees of Freedom	Mean Squares	F value
Between Treatments	$SS_{Treatments}$	*a - 1*	$MS_{Treatments}$	$F_0 = \dfrac{MS_{Treatments}}{MS_{Error}}$
Within Treatments	SS_{Error}	*N - a*	MS_{Error}	
Total	SS_T	*N - 1*		

6.4 ACCEPTANCE SAMPLING TECHNIQUE

This section introduces the acceptance sampling technique and explains the procedure and application of the acceptance sampling technique.

Acceptance sampling is a technique to accept a lot or reject it based on a few samples when it is not possible to test the entire lot. For example, if every egg in the lot is tested (by breaking it), there will be none left to consume. If none of the eggs is tested, the supplier might sell rotten eggs. The acceptance sampling technique will limit the number of samples that have to be tested before the entire lot is accepted or rejected depending upon the error tolerance in the test procedure.

Acceptance sampling is an important field of statistical quality control that was popularized by Dodge and Romig and originally applied by the U.S. military to the testing of bullets during World War II. Acceptance sampling is "the middle of the road" approach between no inspection and 100% inspection. A point to remember is that the main purpose of acceptance sampling is to decide whether or not the lot is likely to be acceptable, not to estimate the quality of the lot [10].

The Acceptance sampling technique is employed when:

1. The testing procedure itself renders the product tested unfit for the application for which it is developed.
2. The resources to conduct a full 100% test of every product in the lot are unavailable, unlimited or unrealistic.
3. The duration of the test to conduct a full 100% test of every product is unavailable or unlimited or unrealistic.

6.5 ACCEPTANCE SAMPLING: TYPES AND TERMS

There are different types of acceptance sampling plans, each type defining a sampling scheme and a pre-defined set of rules for decision making. The decision that is made, based on the number of defectives that are found while testing the lot, can be to accept the entire lot, reject the entire lot or to continue testing to make a decision.

The most common types of acceptance sampling plans are:

1. Single Acceptance Sampling Plan
2. Double Acceptance Sampling Plan
3. Multiple Acceptance Sampling plan
4. Sequential Acceptance sampling Plan
5. Accept on Zero Sampling Plan

Single Acceptance Sampling Plan

In a single acceptance sampling plan, a single sample consisting of one or more items is selected from the entire lot. The number of defectives within the sample is recorded by testing every item in the sample. The entire lot is either accepted or rejected based on the percentage of defectives found within the sample selected. These plans are often represented as (*n, c*) plans, where *n* is the size of the sample which is comparatively less than the lot size *N*. The parameter *c* is the maximum number of defectives that will be tolerated within the sample size *n*. The entire lot *N* will be rejected if there are more than *c* defectives in *n* samples. The entire lot *N* will be accepted if there are no defectives or less than *c* defectives in the *n* samples. Single acceptance sampling plans, although the most common and easy are not very effective and/or efficient in terms of the average number of samples needed [10].

Double Acceptance Sampling plan

In a double acceptance sampling plan, a maximum of two samples with one or more items are selected and tested from the entire lot. These plans are represented as (n_1, a_1, r_1, n_2, a_2, r_2) plans. n_1 and n_2 are the sample sizes of samples one and two, respectively. a_1 and a_2 are accept numbers for samples one and two respectively. r_1 and r_2 are rejection numbers for samples one and two, respectively. In a double acceptance sampling plan, every item in the first sample is tested and the number of defectives is recorded. Unlike the single acceptance sampling plan, there are three outcomes of this test: Accept lot, Reject lot or Test Second Sample. If the decision is to test the second sample (number of defectives greater than acceptance number and less than rejection number), every item in the second sample is tested and the number of defectives is recorded. The defective items from the two samples are combined and compared against a_2 and r_2 to decide whether to accept or reject the entire lot *N*. The lot is accepted if the combined defectives are less than or equal to a_2. The lot is rejected if the combined defectives are greater than or equal to r_2. The value of $r_2 = a_2 + 1$, to guarantee a result in the second sample. The usefulness of a double acceptance sampling plan is greater than the single acceptance sampling plan because it can overcome the non-conclusive result of single sampling.

Multiple Acceptance Sampling Plan

The multiple acceptance sampling plan is an extension of the double acceptance sampling plan where more than two samples of one or more items are selected to decide whether to accept or reject the entire lot *N*. The advantage of a multiple acceptance sampling plan is the smaller size of each individual sample.

Sequential Acceptance Sampling Plan

This is the most complicated of all acceptance sampling plans and also the most efficient. In this plan, single items are selected sequentially at random from the entire, tested and the results are recorded. At the end of testing each item, there are three possibilities: accept the lot, reject the lot and test another item from the lot. This process continues until the percentage defectives from the items tested exceeds the tolerance value or falls below the acceptable value. Unlike previous sampling plans, the sample size is not fixed in this plan.

Accept on Zero (AoZ) Sampling Plan

The AoZ sampling plans are very similar to the single, double and multiple sampling plans, but are designed to provide greater consumer protection with less inspection than the corresponding military standard plans. All previous plans accept the fact that in reality there are always defect in any product and accept a lot with defect rates that are considered acceptable. In AoZ sampling, the value of errors tolerated is zero (c = 0). A sample with one or more items is selected from the lot and upon finding any error, the entire lot is rejected. The lot is accepted only if there are absolutely no errors in the sample. The accept on zero sampling plan is integrated into the interoperability test methodology. A single error is sufficient to comment on interoperability.

Determining the type of acceptance plan to use, the sample size, number of samples, the power of the test and resources required for the test all depend upon the properties of the acceptance sampling plan [11]. The properties of the acceptance sampling plan include:

1. Acceptable Quality Level
2. Lot Tolerance Percentage defective
3. Producer's Risk
4. Consumer's Risk
5. Operating Characteristic Curve

Acceptable Quality Level

Acceptable Quality Level (abbreviated as AQL) is the percentage defective that is a minimum requirement of the product. The producer will supply the product such that there is a high probability of acceptance by the consumer when the lot has a percentage defective that is less than or equal to the AQL.

Lot Tolerance Percentage Defective

Lot Tolerance Percentage Defective (abbreviated as LTPD) is a higher defect level (LTPD > AQL) unacceptable to the consumer. The consumer will design an acceptance sampling plan such that there is a very low probability of accepting the lot with a percentage defective greater than or equal to LTPD.

Producer's Risk (α)

Producer's risk is also called *Type I Error*. It is the probability of rejecting a lot with a defect level equal to AQL. The producer suffers when this error occurs because a lot with percentage defective less than or equal to AQL was rejected although the lot was actually acceptable.

Consumer's Risk (β)

Consumer's risk is also called *Type II Error*. It is the probability of accepting a lot with a defect level equal to LTPD. The consumer suffers when this error occurs because a lot with a percentage defective greater than or equal to LTPD was accepted although the lot was actually unacceptable.

Operating Characteristic Curve

The Operating Characteristic Curve (abbreviated as OC Curve) is a graph plotting the percentage defective on the x-axis and the probability of acceptance of the lot on the y-axis. The OC curve is the primary tool for displaying and investigating the properties of an acceptance sampling plan.

6.6 DEVELOPING A SINGLE ACCEPTANCE SAMPLING PLAN

Understanding and developing a single acceptance sampling plan is the first step involved in the acceptance sampling technique and will help in analyzing the OC curve of different acceptance sampling plans.

The single sampling plan can be easily developed using MIL Standard 105D. This document is essentially a set of individual plans organized in a system of sampling schemes. A sampling scheme consists of a combination of a normal sampling plan, a tightened sampling plan, and a reduced sampling plan plus rules for switching from one to the other.

The steps in the use of the standard can be summarized as follows:

1. Decide on the AQL.

2. Decide on the inspection level. The inspection level determines the relationship between the lot size and the sample size.
3. Determine the lot size.
4. Enter the table to find the sample size code letter.
5. Decide on the type of sampling to be used. The standard offers single, double and multiple sampling plans.
6. Enter the proper table to find the plan to be used.
7. Begin with normal inspection; follow the switching rules and the rule for stopping the inspection if necessary.

The second method is to calculate the sample size and acceptance number from the acceptance sampling plan parameters and to further plot the OC curve for individual values of the percentage defective. The procedure to calculate and develop a single acceptance sampling plan can be summarized as:

1. Decide on AQL, LTPD, α and β.
2. The probability of acceptance for a percentage defective of AQL is 1-α. The probability of acceptance for a percentage defective of LTPD is β. The OC curve will pass through these two points.
3. The sample size n and the acceptance number c are the solution to the two simultaneous non-linear equations:

$$1-\alpha = \sum_{d=0}^{c} \frac{n!}{d!(n-d)!} AQL^{d}(1-AQL)^{n-d}$$

$$\beta = \sum_{d=0}^{c} \frac{n!}{d!(n-d)!} LTPD^{d}(1-LTPD)^{n-d}$$

4. Use iterative computer algorithms to obtain an approximate solution to the equations in step 3.
5. Assume the distribution of the number of defectives d in a random sample on n items is approximately binomial with parameters n and p where p is the fraction of defectives per

lot. The probability of observing exactly d defective items is given by the binomial distribution:

$$P(d) = f(d) = \frac{n!}{d!(n-d)!} p^d (1-p)^{n-d}$$

The probability of acceptance is the probability that d is less than or equal to c.

$$P_a = P\{d \le c\} = \sum_{d=0}^{c} \frac{n!}{d!(n-d)!} p^d (1-p)^{n-d}$$

Refer to Table 6-3 and Figure 6-1 for an example of a (52, 3) single acceptance sampling plan.

Table 6-3: OC Curve – (52, 3) Single Acceptance Sampling Plan

Data Source: NIST/SEMATECH e-Handbook of Statistical Methods

Percentage Defective	Probability of Acceptance
0.01	0.998
0.02	0.980
0.03	0.930
0.04	0.845
0.05	0.739
0.06	0.620
0.07	0.502
0.08	0.394
0.09	0.300
0.10	0.223
0.11	0.162
0.12	0.115

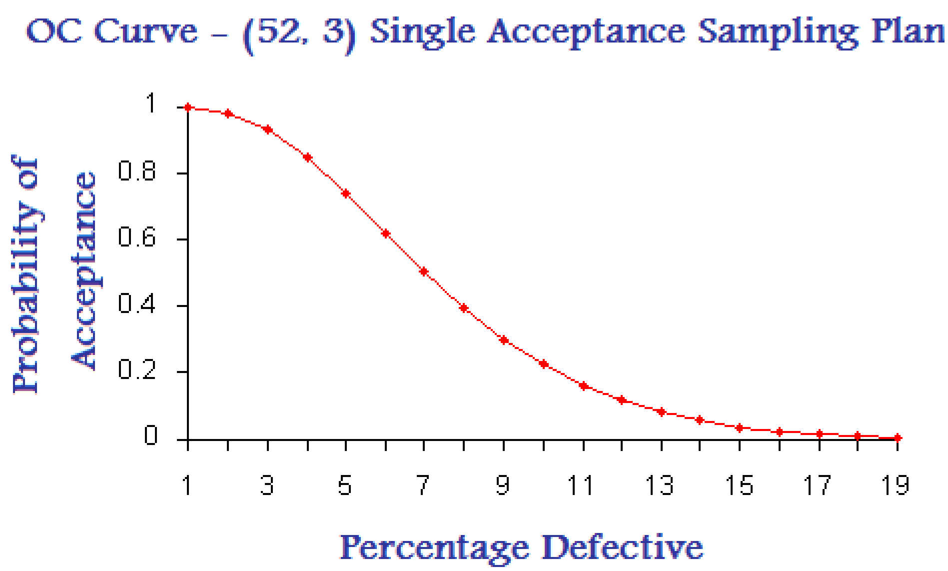

Figure 6-1: OC Curve – (52, 3) Single Acceptance Sampling Plan

6.7 DEVELOPING A SEQUENTIAL ACCEPTANCE SAMPLING PLAN

In this type of sampling, items are tested one after the other. The total number of items to test before coming to a conclusion will depend on the nature of the test results. Refer to Figure 6-2 for a graphical representation of the sequential acceptance sampling technique.

The x-axis represents the total number of items tested. The y-axis represents the number of items found defective within the total items tested. The red line is called the *rejection line*. The equation of the rejection line is $x_r = h_2 + sn$, where 'h_2' is the y-intercept of the rejection line and s is the slope of the rejection line. The green line is called the *acceptance line.* The equation of the acceptance line is $x_a = -h_1 + sn$, where '$-h_1$' is the y-intercept of the acceptance line and s is the slope of the acceptance line. Because the slope of both the acceptance line and rejection line are equal, the two lines are parallel to each other [12].

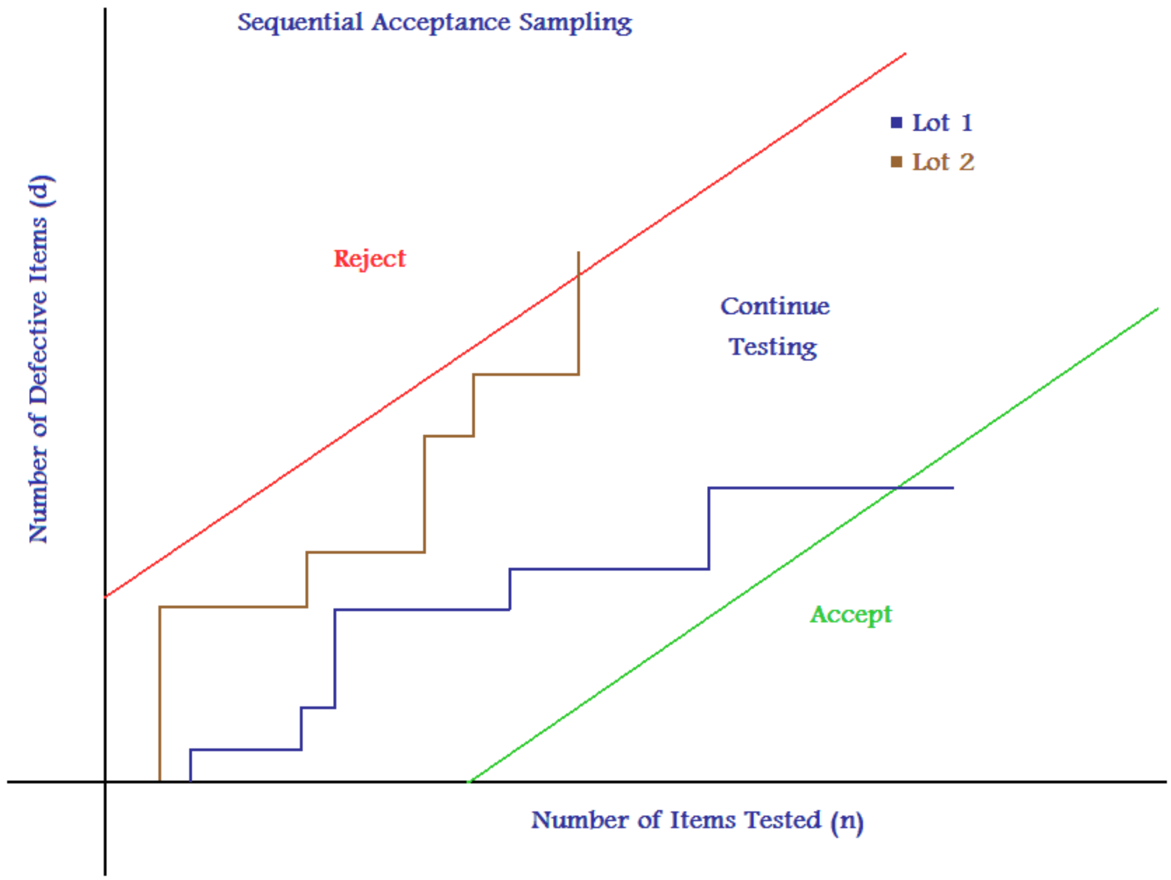

Figure 6-2: Sequential Acceptance Sampling Plan

The slope of the lines and the y-intercepts can be calculated using the formulae:

$$k = \log \frac{LTPD(1 - AQL)}{AQL(1 - LTPD)}$$

$$s = \frac{\log \dfrac{1 - AQL}{1 - LTPD}}{k}$$

$$h_1 = \frac{\log \dfrac{1 - \alpha}{\beta}}{k}$$

$$h_2 = \frac{\log \dfrac{1 - \beta}{\alpha}}{k}$$

The cumulative calculated number of defects versus the total number of items tested is plotted on the graph. If the plotted point falls within the parallel lines the testing continues and another item has to be tested before coming to a conclusion. If the point falls below the green acceptance line, the lot is accepted. If the point falls above the red rejection line the lot is rejected. Shown in the graph, Lot 1 is accepted and Lot 2 is rejected.

6.8 DEVELOPING ACCEPT ON ZERO SAMPLING PLAN

The procedure to calculate the sample size associated with the lot size for AoZ sampling is very similar to the single sampling plan described before.

The AoZ sampling plan can be directly implemented as described in the "Zero Acceptance Number Sampling Plans, 4th Edition" by Nicholas L. Squeglia. The sample size is specified in this book as a function of lot size and index values (tolerable percentage defective) is widely accepted and used [13].

The steps to use the above can be summarized as follows:

1. Decide on the Index Value.
2. Determine the lot size.
3. Enter the "Table 1-a" to find the corresponding sample size.

There is another method to calculate (or approximate) the sample size. When the lot size to sample size ratio is greater than or equal to 10, the sample size can be approximated using binomial distribution equation [14], [15].

When the sample size (n) is insignificant when compared to the lot size (N), i.e., when $N \geq 10n$, testing a single item from the lot has an equal probability of being either a defective or good item if a 50% defective rate is assumed.

The characteristics of a binomial random variable are:

1. The experiment consists of finite trials.
2. There are only two possible outcomes for each trial: Success or Failure.
3. The probability of Success remains the same from trial to trial. The probability of failure will also remain the same from trial to trial. The sum of probability of Success and Failure equals one.
4. The trials are independent of each other.

The probability of y successes in n total trials is:

$$P(y) = \frac{n!}{y!(n-y)!} p^{y} q^{n-y}$$

Let the known acceptable percentage defective in the lot (LTPD) be 5% which means that after testing the sample if no item is found defective then the entire lot is accepted because the percentage defective is less than 5%. Then the percentage of good items in the lot is at least 95%. From the binomial distribution, the probability of finding no defectives in n successive tests is

$$P(No\ Errors) = (1 - known\ \ percentage\ defective)^{n}$$

Therefore if no errors are found after testing n items, then with a high confidence this entire lot is good.

$$\beta = (1 - LTPD)^{n}$$

$$n = \frac{\log \beta}{\log(1 - LTPD)}$$

Where, β is probability of acceptance of the lot and LTPD is the lot tolerance percentage defective.

The sample size of the lot can be calculated using the equation above. If all n items are tested and found good, then with a confidence level of $(1-\beta)$, it can be concluded that the error percentage is definitely less then LTPD and the entire lot is accepted. The entire lot is rejected if a single defect is found.

7.0 OVERVIEW OF LABVIEW

LabView, though conceptually viewed as any other conventional programming language, is unique that here the program is written graphically rather than following a textual syntax. It uses icons analogous to functions instead of text. LabView uses dataflow programming similar to sequential program execution in C-language, where the flow of data from left to right through graphical sub-routines determines execution. LabView offers almost all the features of any other programming language and sometimes even more through effective utilization of the processor cores and threading without the need to change or update the compiler on part of the user. It is possible to integrate C-code, MATLAB code or VHDL code into a LabView program inviting traditional programmers to perceive the new dimension in programming.

Deciding to use LabView programming language is an excellent choice when working with hardware devices through remote connection and when the data is to be presented to the user by graphs. Graphical data representation is comparatively inbred into the development of LabView more than any other commercial programming languages that are used to develop windows applications. The RF Signal Generator (RFSG) and the RF Signal Analyzer (RFSA) used in this research are programmed using LabView. Therefore, to understand remote operation of all the test setup through LabView, it is essential to get acquainted with the basics of the software first. The RFSA and the RFSG used in the setup are from National Instruments (NI) and since LabView is also developed by NI, there is a tight integration among the software and hardware (National Instruments, 2008).

LabView is not only simple to program, but it is also very easy to understand. The main reason for this is that the user need not follow a strict syntax to develop or understand the code.

Data flows through wires from one sub VI to another. Just by understanding inputs and outputs of each VI, one can comprehend the overview of the program.

LabView programs or sub-routines are called virtual instruments, or VIs, because their appearance and operation imitate physical instruments. LabView has a variety of instruments like up-samplers, encoders, decoders, modulators, demodulators and filters all implemented in software. Every VI uses functions that manipulate input from the user interface or other sources and display that information or move it to other files or hardware devices.

A VI can be separated into three main components:

1. Front Panel
2. Block Diagram
3. Icon and Connector Pane

7.1 FRONT PANEL

The front panel is the graphical user interface of the VI. The user transfers inputs and can examine the outputs in the front pane. The front panel is typically built using controls, push buttons, numerical inputs, indicators (LEDs) and graphs.

Figure 7-1 shows the front panel of a VI that generates a sine wave based on amplitude and frequency inputs selected by the user. The VI also outputs the RMS voltage value of the generated sine waveform. Another input to the VI is the stop button which stops generating the sine wave and terminates the execution of the program

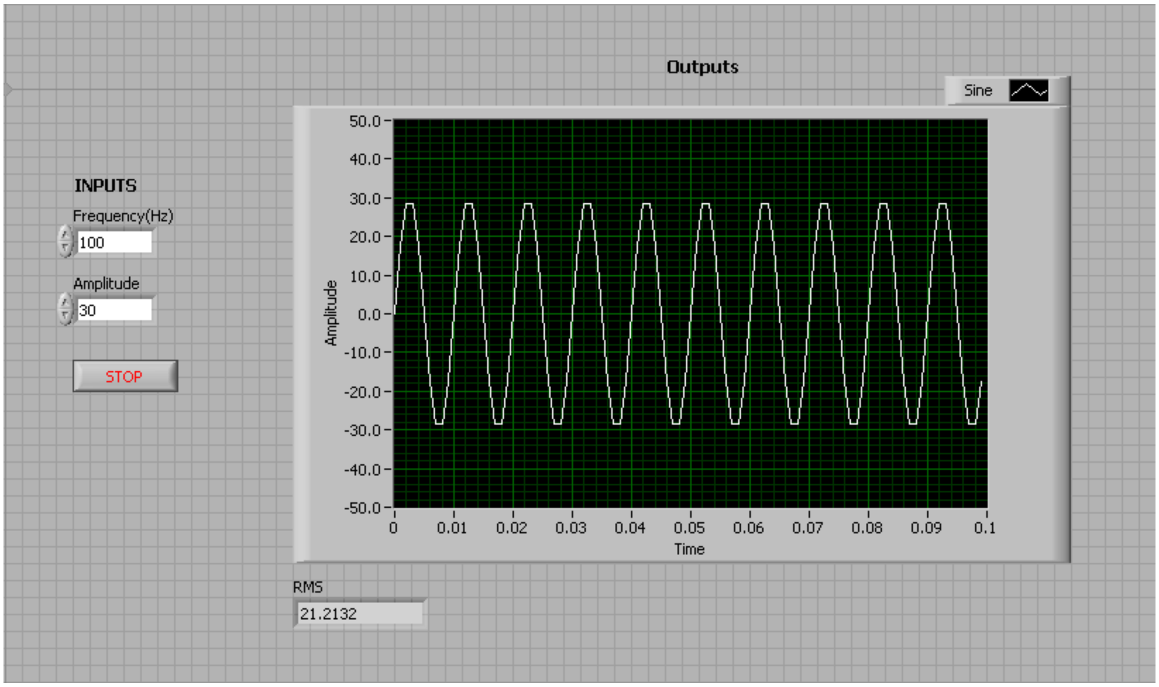

Figure 7-1: Generate Sine Wave VI – Front Panel

In the example front panel, all the inputs have been assembled to the left and all outputs are assembled to the right. As the frequency and amplitude inputs are varied on the front panel, the waveform in the graph (output) also changes proportionally.

7.1.1 Building a Front panel

The front panel is built with controls and indicators, which are the interactive input and output terminals of the VI, respectively. Examples for controls are knobs, push buttons, dials, and other input devices. Examples for indicators are graphs, LEDs, and other displays. Controls simulate instrument input devices and supply data to the block diagram of the VI. Indicators simulate instrument output devices and display data the block diagram acquires or generates.

To add an indicator to the front panel, right click anywhere on the free portion of the front panel. A *controls window* is displayed as shown in Figure 7-2.

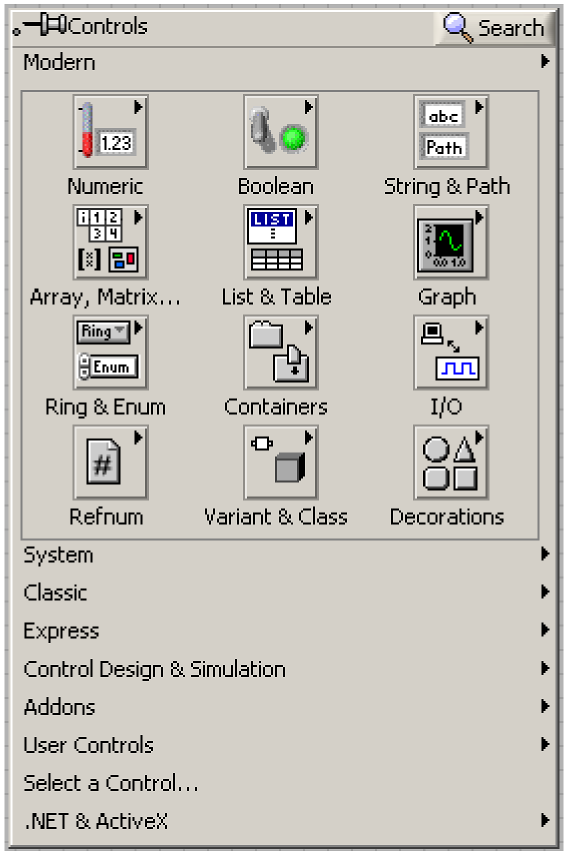

Figure 7-2: Controls Window in Labview 8.2

The *controls window* has all the terminals, divided and categorized into many types (Numeric, Boolean, Express, Graph etc.). A terminal can be found on the controls window in more than one category. The type of the terminal can be tuned and adjusted by modifying its properties.

Aligning, distributing, grouping, locking and resizing objects can be done in LabView just like any other windows based program.

Another accessible and convenient feature of LabView is the *search* option located in the upper right corner of the controls window. For example, if it is required to find an indicator, and if its category is explicit or unknown, an appropriate keyword can be entered in the *search window* to display a choice of indicators. The extent of the different functions available in LabView can be discovered using this feature.

The terminals in LabView support all the variable types possible in any other conventional programming language such as C-language.

7.2 BLOCK DIAGRAM

Once the front panel is built (the inputs and outputs are decided and arranged), the next step is to insert the code in the block diagram using graphical representation of functions or sub-VIs. Front panel objects appear as terminals on the block diagram. Figure 7-3 illustrates the corresponding block diagram for the Generate Sine Wave VI.

As shown, the entire source code is put in a *while* loop so that it executes continuously. The *while* loop breaks or terminates to execute when the *stop button* on the front panel is pressed. The “Simulate Signal” sub-VI (a VI used as a function inside another VI is referred to as a sub-VI) accepts the inputs Frequency and Amplitude from the front panel. The output of the VI is a sine wave. This sine wave is branched into two components, one going to the waveform graph display and the other going as input to the ”Amplitude and Level Measurements” sub-VI. The output of this VI is programmed to calculate the RMS Voltage of the input waveform, in this case the sine wave

Notice that all the terminals (inputs and outputs) of the program (Frequency, Amplitude, Waveform, RMS Voltage and Stop) are shown on the front panel. Double-clicking a terminal on the block diagram will highlight the corresponding control or indicator displayed on the front panel.

Terminals are entry and exit ports that exchange information between the front panel and the block diagram. Data entered into the front panel controls enter the block diagram through the control terminals. During execution, the output data flows to the indicator terminals, where they exit the block diagram, enter the front panel, and appear in front panel indicators.

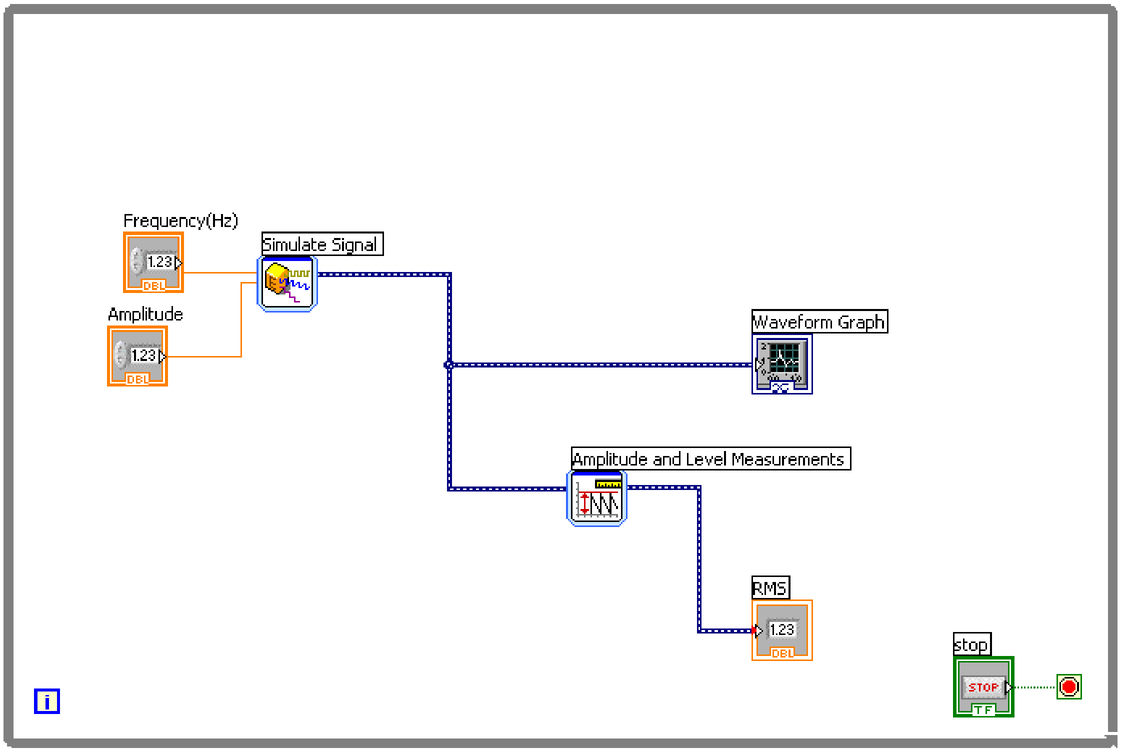

Figure 7-3: Generate Sine Wave VI – Block Diagram

7.2.1 Building a Block Diagram

Building a block diagram is very similar to building a front panel. It is a good practice to first decide on the inputs and outputs before developing the algorithm and data analysis a program. Hence the objects on the front panel are chosen before developing the block diagram. In some cases, the opposite approach might make program development more reasonable, and it is up to the experience of the designer to select the appropriate development plan. One can create a control or indicator by right clicking on the input or output of a VI and select create control or indicator to put the corresponding terminal (object) on the front panel. The advantage of using this method is that all the properties (type, format and precision) of the object are selected to match the data type.

When the front panel is built, the block diagram would already have the terminals (in this case Frequency, Amplitude, Graph and RMS). The next step is to put in a function that will accept the Frequency and Amplitude inputs and generate a sine wave.

As in the front panel, right clicking anywhere on the white portion of the block diagram opens the *functions window*. The *functions window* is shown in Figure 7-4.

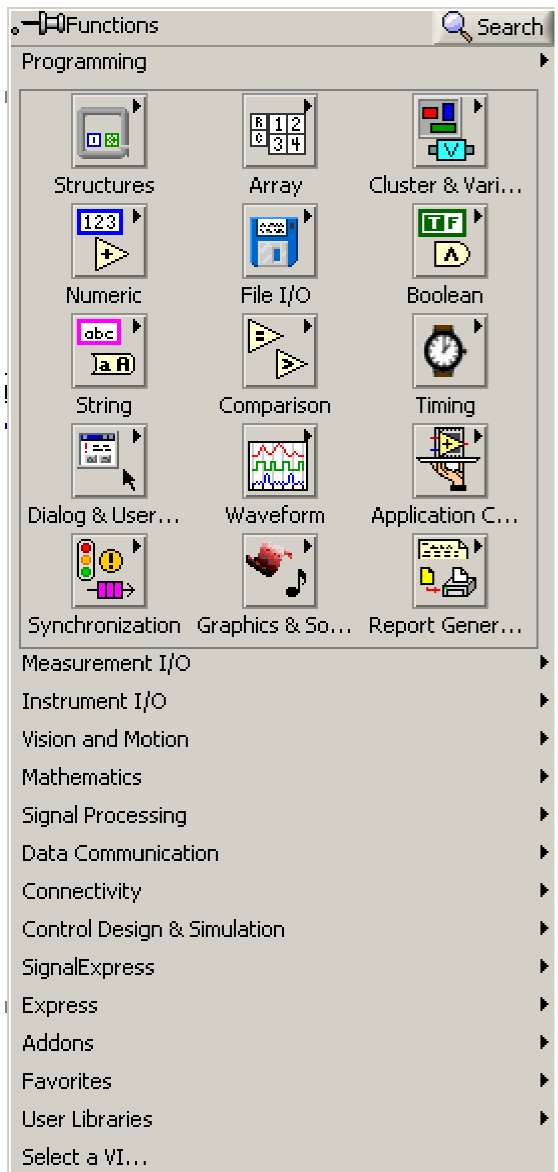

Figure 7-4: Functions Window

If the category of the required VI is known, it can be selected manually and placed on the block diagram. Otherwise, similar to the *controls window*, the *search* option can be utilized to find the necessary functions available and research the LabView offered built-in functions. After selecting and arranging all the functions, the block diagram will look as shown in Figure 7-5.

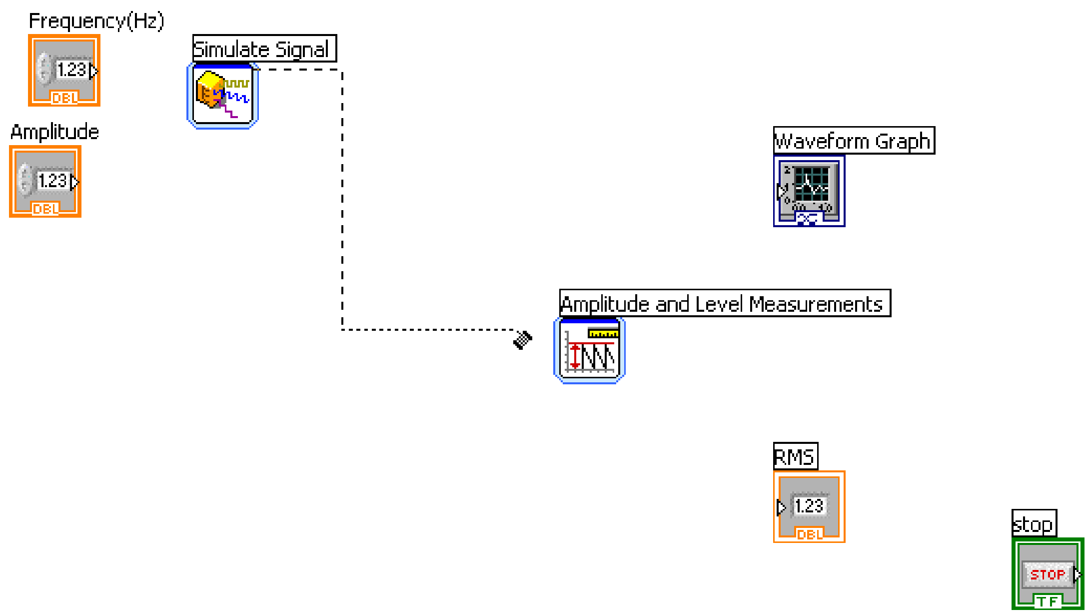

Figure 7-5: Generate Sine Wave VI – Block Diagram Unwired

The next step is to connect (wire) the different modules (sub-VIs and terminals) on the block diagram. The terminals and sub-VIs should be connected with wires because in LabView data are transmitted between functions through wires. Each wire has a single data source, but can be wired into many sub-VIs and functions (sinks) that need to read the same data.

The color of the terminal is an indicator of its type (integer, float/double or character) which the programmer can use to select the appropriate terminal properties to connect the wire to. The user must wire all required block diagram terminals. Otherwise, the VI is “broken” and will not execute.

The wiring tool is used to manually connect the terminals from one block diagram node to the terminals on another block diagram node. The cursor point of the tool is the tip of the unwound wire spool. When the tip of the unwound wire is clicked on the terminal, it starts to unroll a broken wire. When the broken wire is connected to the correct input of a VI of compatible type, the wire becomes solid. The color of the wire is same as its terminal and the source.

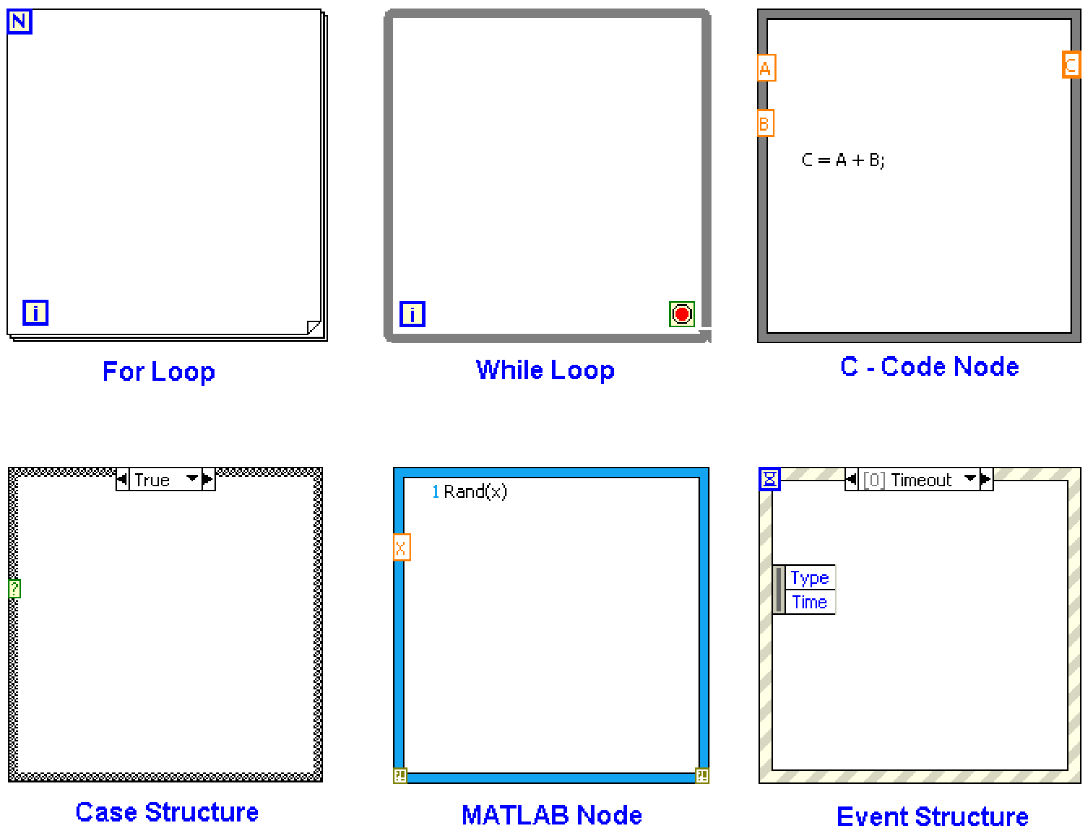

Figure 7-6: Structures in Labview

LabView also supports the structures of conventional programming languages like *while*, *for loop* etc. LabView also accepts 'C' code or MATLAB code to be put into the block diagram using functions node and math-scripts node. Another structure supported in windows application development programming languages like VB.Net or C#.Net is the event triggered module execution. Here a certain module or code is executed when the user triggers an event like clicking a button or entering a value. LabView supports such a program structure called *Time Event*. The structures in LabView are shown in Figure 7-6.

7.3 ICON AND CONNECTOR PANE

Icon is a graphical representation of the VI. It is always shown at the top right corner of the front panel window. Making an icon will make it easy to identify a particular VI when using it as a sub-VI in another VI. After all, LabView is a graphical programming language.

In the Generate Sine Wave VI developed in the example, it is possible to combine Simulate Signal and Amplitude and Level Measurements into a single VI called *Generate Sine and calculate RMS*. This combination can be used in another VIs. The first step in generating a sub-VI is to define an icon. The user can edit the icon using the *Icon Editor window*. *Icon Editor window* is shown in Figure 7-7.

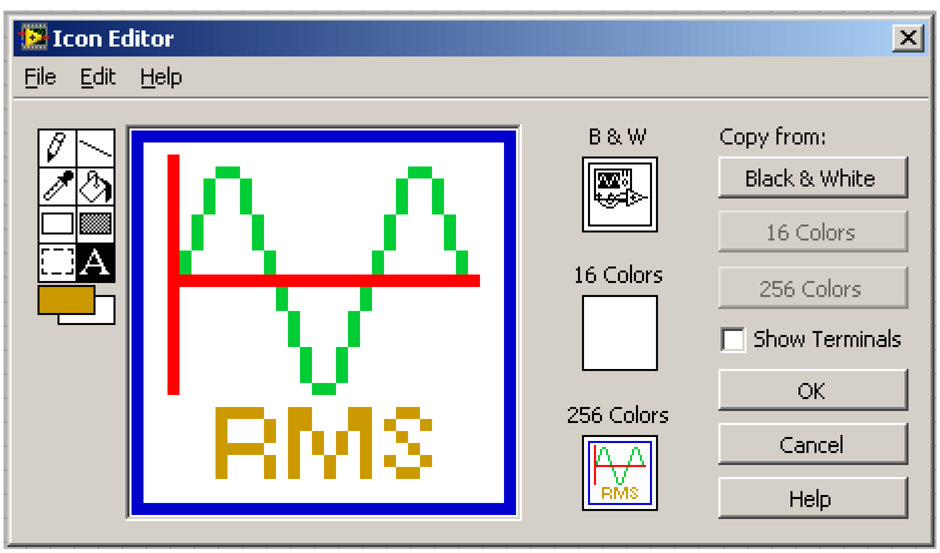

Figure 7-7: Icon Editor Window for Generate Sine and calculate RMS

In a large design, a section of a VI can be converted into a Sub-VI by using the Positioning tool to select the section of the block diagram and selecting Create Sub –VI in the *edit menu*. An icon for the new Sub-VI replaces the selected section of the block diagram. LabView creates both controls and indicators for the new Sub-VI and wires the Sub-VI to the existing wires.

Once the new icon is composed, the user is required to define the input and outputs terminals of sub-VI. VI Connector can be used to define terminals of the sub-VI. A sub-VI is developed with terminals and icon as shown in Figure 7-8.

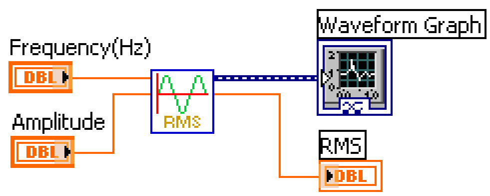

Figure 7-8: Generate Sine and Calculate RMS Icon

This VI can be used in other VIs similar to functions in any other programming language. It must be noted that Labview does not allow a VI to call itself recursively unless it is specifically programmed to do so. This is called re-entrant execution support of a VI. In this case, every instance of the sub-VI is allocated different memory space.

8.0 RADIO FREQUENCY SIGNAL ANALYZER

A Radio Frequency Signal Analyzer, as the name suggests, is typically used to capture the RF communication between two or more wireless devices. It acts as a transducer, converting the RF energy in the environment, used as a channel by wireless devices, and converting it into digital data that can be processed and analyzed by the PC and most importantly making RF signals visible to the human eye.

There are many commercial RFSAs available in market like the ni5660/61 and Keithley 2810. There are RFSAs which have a wide frequency range of capture, and there are some made specifically to capture signals in a particular band of frequencies. Another major specification to look at while selecting a RFSA is the Resolution Bandwidth. The Resolution Bandwidth is related to the minimum sampling rate possible and affects the reconstruction of the signal after demodulation.

Most RFSAs give their output in IQ data format also called the raw data format which is not demodulated. More about IQ data and its significance will be explained in section 9.3. This IQ data can be loaded into LabView or any other similar software for processing, demodulation and analyzing. The RFSA used in the test setup is the ni5660. This is a product developed by National Instruments in 2006 (NI, 2008).

The ni5660 is an industry standard RFSA from NI, with a very wide frequency range. It can capture signals with frequencies ranging from 9kHz to 2.7GHz. It has a wide adjustable Resolution Bandwidth and for acquisitions with less than 1.25MHz, it has eight discrete bandwidth settings and corresponding sampling rates. It has a 10 MHz oven-controlled crystal oscillator (OCXO) that is the reference clock for all timing circuits in the module. The full signal input range is 30dBm. It also has a 64MB built in memory. NI – RFSAs can be connected to the computer using a PCI bus which allows very high speed data transfers on the order of mega bytes [16].

The ni5660 is divided into two modules; the ni5600 which is the down-converter module and the ni5620 which is the digitizer module. The block diagram representation of the ni5660 RFSA is shown in Figure 8-1.

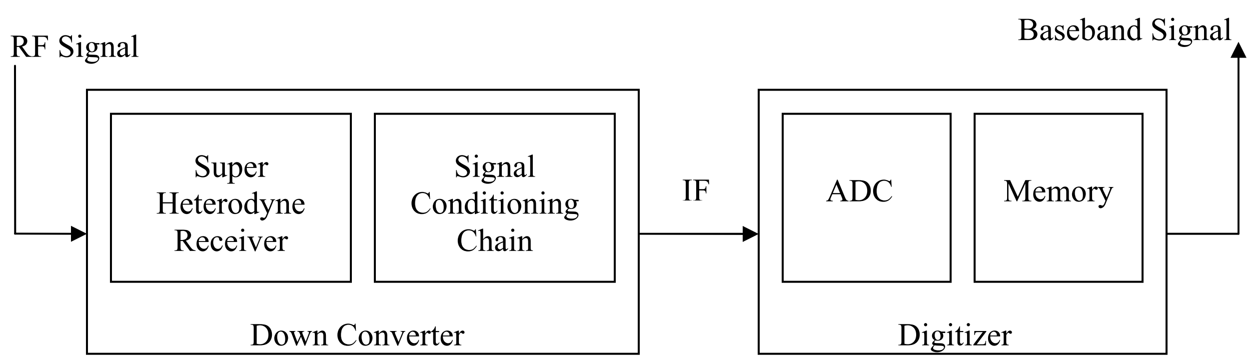

Figure 8-1: Block Diagram of ni5660 RFSA

The RF signal is taken as input by the down-converter. The NI 5600 down-converter module performs two primary functions. They are frequency shifting, or down conversion, and input signal conditioning. Frequency shifting is performed using a tunable oscillator in the super-heterodyne signal chain. Input signal conditioning is accomplished using three stages of mixer conversion and two sets of gain attenuators whose levels are programmable. The first set of attenuators can be set to minimize distortion and other spurious signals when input levels are high and to minimize noise when input levels are low. The second set of attenuators is in the second intermediate frequency path before the third mixer and ensures an appropriate output signal level even if the first mixer is intentionally driven into compression. These attenuators are also set when performing linearity measurements. The NI 5620 is an IF high-speed digitizer module featuring a 14-bit analog-to-digital converter (ADC) with deep onboard sample memory.

Offering sample rates of 1 kS to 64 MS/s and distortion-free performance, it complements the NI 5600 RF down-converter module in analysis applications. [Adapted from NI – RFSA Help]

The physical connections between the ni5600 down-converter module and the ni5620 digitizer module are shown in Figure 8-2.

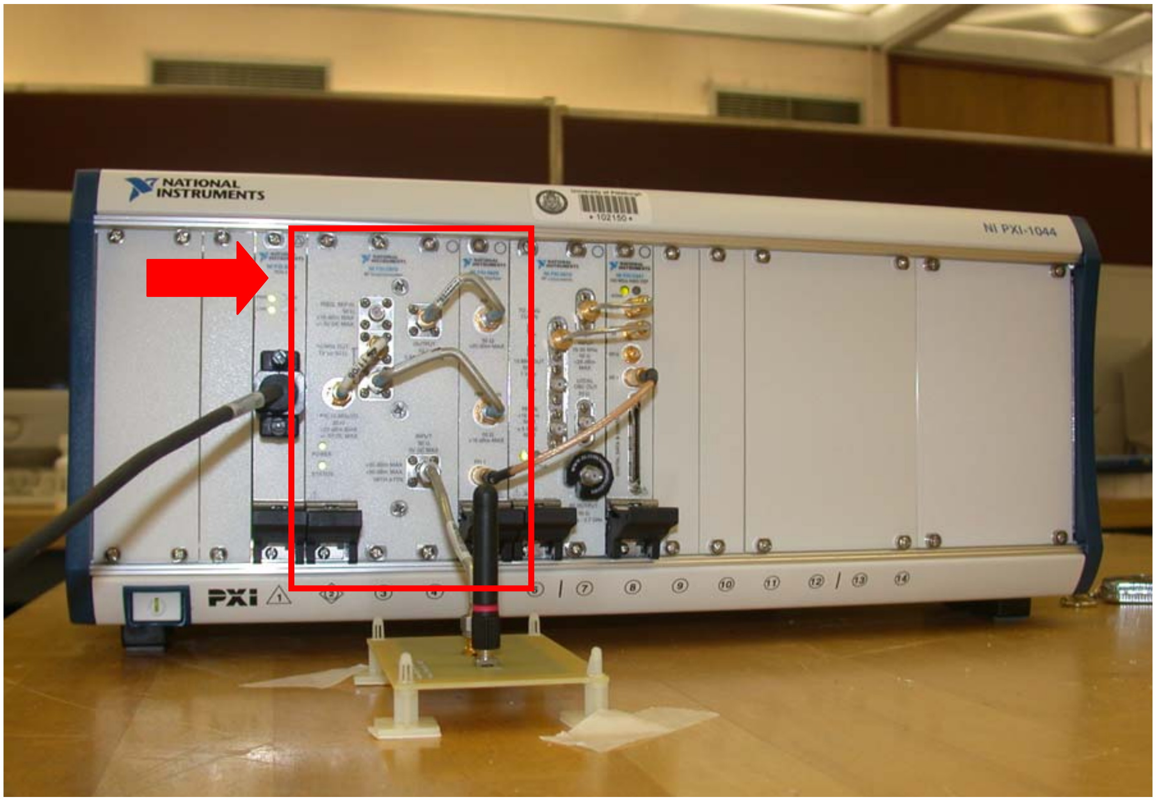

Figure 8-2: ni5600 + ni5620 = ni5660. Physical Connections

8.1 NI 5660 SIGNAL PATHS

A signal takes the following path from the RF Signal Analyzer wireless antenna to the PXI controller:

1. A signal enters the RF Signal Analyzer through the INPUT front panel connector of the NI 5600 RF down-converter module.
2. The NI 5600 RF down-converter module "zooms in" on a 20 MHz block of spectrum and frequency-translates it to center around 15 MHz. The translated IF signal is sent to the NI 5600 down-converter module OUTPUT connector.
3. The IF signal is passed from the NI 5600 RF down-converter module front panel OUTPUT connector to the NI 5620 IF digitizer module front panel INPUT connector.
4. The NI 5620 IF digitizer module filters and conditions the signal and applies gain and dither.
5. The Analog-to-Digital Converter (ADC) converts the signal from analog to digital.
6. The data are sent to onboard memory.
7. The data are transferred to the host computer. [Adapted from NI – RFSA Help]

8.2 CONFIGURING THE NI5660

The NI – 5660 can only be configured using Labview. It has no buttons on the chassis for programming ability. Some of the important VIs used in configuring NI – 5660 are discussed below.

8.2.1 ni5660 Initialize

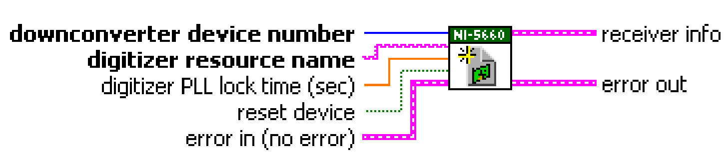

Figure 8-3: ni5660 Initialize VI

This VI creates a new instrument driver session to the RF signal analyzer, using the down-converter device number and the digitizer resource name specified. It sends initialization commands to reset both hardware modules to a known state necessary for NI-RFSA operation. Next it sets the RF down-converter module onboard clock as the RF Signal Analyzer reference clock source. When all the phase locked loops (PLLs) lock (synchronize) correctly, the STATUS light on the RF down-converter module is activated. When programming the ni5660, this VI must always be used first and hence the name *initialize*.

8.2.2 ni5660 Configure for IQ

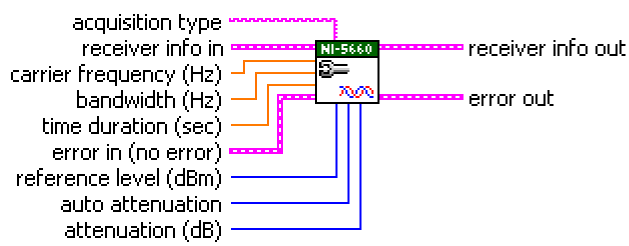

Figure 8-4: ni5660 Configure for IQ VI

This VI configures the RF Signal Analyzer hardware to acquire a time-domain signal with IQ settings you specify. Carrier frequency, bandwidth, and acquisition time settings define the IQ data. You can configure the acquisition to be finite or continuous. The ni5660 is setup to the continuous acquisition type mode is when a continuous data stream is to be captured. This VI configures the reference level and attenuation settings used by the RF down-converter module, and the horizontal settings and acquisition type used by the IF digitizer module.

8.2.3 ni5660 Read IQ

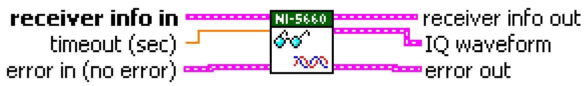

Figure 8-5: ni5660 Read IQ VI

This VI returns the waveform acquired by the RF Signal Analyzer. This VI is used when acquiring a finite signal which can be stored in the buffer memory of the device. This VI initiates an acquisition and returns both a scaled voltage waveform with timing information, and IQ data computed through a process of filtering, decimation, and down-conversion. It is this raw data that are taken as input by the PC and used for demodulation.

8.2.4 ni5660 Initiate IQ

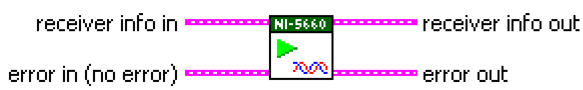

Figure 8-6: ni5660 Initiate IQ

This VI initiates an IQ waveform acquisition. This does roughly half the work done by ni5660 Read IQ. This VI is used when setting up the ni5660 for continuous RF data acquisition.

8.2.5 ni5660 Fetch IQ

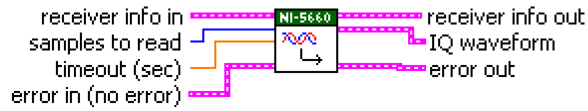

Figure 8-7: ni5660 Fetch IQ VI

This VI returns the IQ waveform acquired by the RF Signal Analyzer during a previously initiated acquisition. This VI returns IQ data computed through a process of filtering, decimation, and down-conversion, And will complete the work started by ni5660 Initiate IQ. This VI is programmed in a while loop for continuous acquisition.

8.2.6 ni5660 Close

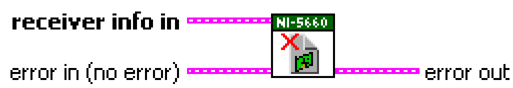

Figure 8-8: ni5660 Close VI

This VI aborts any signal acquisition in progress, terminates the instrument I/O session, destroys the instrument driver session and any attributes. We need to use this VI to end every session with the ni5660 and hence the name *close*.

The VIs discussed in Section 8.2 are to configure the down-converter module and the digitizer module. This is not necessary but a preferred and simple procedure to get started. The down-converter module and the digitizer module can be configured separately one after the other using VIs provided by NI or by developing new VIs. Also the modules can be configured using

GPIB command scripts that can be found in the RFSA programmer's manual. The GPIB scripts can be parsed and the commands can be transmitted to the hardware devices through the PXI bus using the GPIB configuration module present in LabView software package. It is up to the experience of the programmer to develop ingenious procedures to program the signal analyzer pushing it to its limits.

9.0 RADIO FREQUENCY SIGNAL GENERATOR

Radio frequency signal generators (RFSG), as the name suggests, are a form of electronics test equipment typically found in a radio frequency design or test laboratory. These signal generators are used wherever RF signals needs to be supplied to a circuit or unit that is being developed or tested and this source has to be authentic.

An RFSG with arbitrary waveform generation capability is particularly useful when it is necessary to generate complex waveforms (more than one tone or frequency) within published limits of frequency, accuracy and output power.

The RFSG used in this thesis experiment is the ni5671 from NI. The combined functionality of the ni5671 and the modulation toolkit delivers a highly flexible and powerful solution for scientific research and to develop applications in different fields of engineering.

9.1 KEY TERMS IN RFSG

Harmonics and spurious signals

All signal generators produce some level of spurious signals. Harmonics are generally much higher as considerable effort is spent when developing the RFSG, in reducing inter-modulation and other non-harmonically related spurious signals.

Power output

The output from most radio frequency signal generators is of the order of between 10 and 100 milli-watts. This is generally measured in dBm (i.e. dB relative to 1 mW)

Power accuracy

The output of a radio frequency signal generator generally consists of an attenuator. Prior to this, an amplifier with a feedback loop is used to maintain an accurate fixed level. The accuracy of the attenuator then provides the relative accuracy of the individual steps.

Phase noise

The level of phase noise from a radio frequency signal generator will generally fall as the offset from the carrier increases. The actual levels may be given at several points in a specification, and sometimes a plot of the phase noise may be given.

Phase noise levels are measured in terms of dBc / Hz. This is the level of noise in a 1 Hertz bandwidth relative to the level of the carrier. As noise is not on a single frequency but distributed over a frequency range, the wider the measurement bandwidth, the more noise is seen. Accordingly it is necessary to specify a bandwidth and 1 Hertz is taken as the standard.

Accuracy

The accuracy of an RF signal generator is often important. With most RF signal generators using frequency synthesizers, this means that the frequency accuracy is determined by the frequency standard used within the generator. Frequency standards have their accuracy defined with a number of different specifications and these have to be combined in the correct manner to give the overall "accuracy". All accuracy measurements are specified in terms of parts per million (PPM). However there are elements including temperature stability, line voltage stability, aging (i.e. the steady drift with time over many months of the crystal within the reference standard, etc. These need to be added statistically to gain the overall "accuracy" for the radio frequency signal generator.

Modulation formats supported

Originally many RF signal generators had the capability to produce amplitude modulation, AM, and frequency modulation, FM applied. However a large number of modulation formats including various forms of phase shift keying, PSK (including BPSK, QPSK, 8PSK, etc) as well as other more complicated modulation formats including quadrature amplitude modulation, QAM (including 16 and 64 point QAM) need to be used. It is necessary to ensure that the radio frequency signal generator being considered is able to offer the required modulation formats.

9.2 NI5671 FUNCTIONAL BLOCK DIAGRAM

Figure 9-1 shows the functional block diagram of the ni5671 RF Signal Generator. The RFSG can be divided into two main modules. The first module is the ni5441 which is an arbitrary waveform generator and the second module is the ni5610 which is an up-converter. The ni5441 generates the necessary waveforms within the restrictions and criteria provided by the user. This waveform is centered around the intermediate frequency (IF). This signal is up-converted or frequency translated to the desired carrier frequency by the ni5610 up-converter [17].

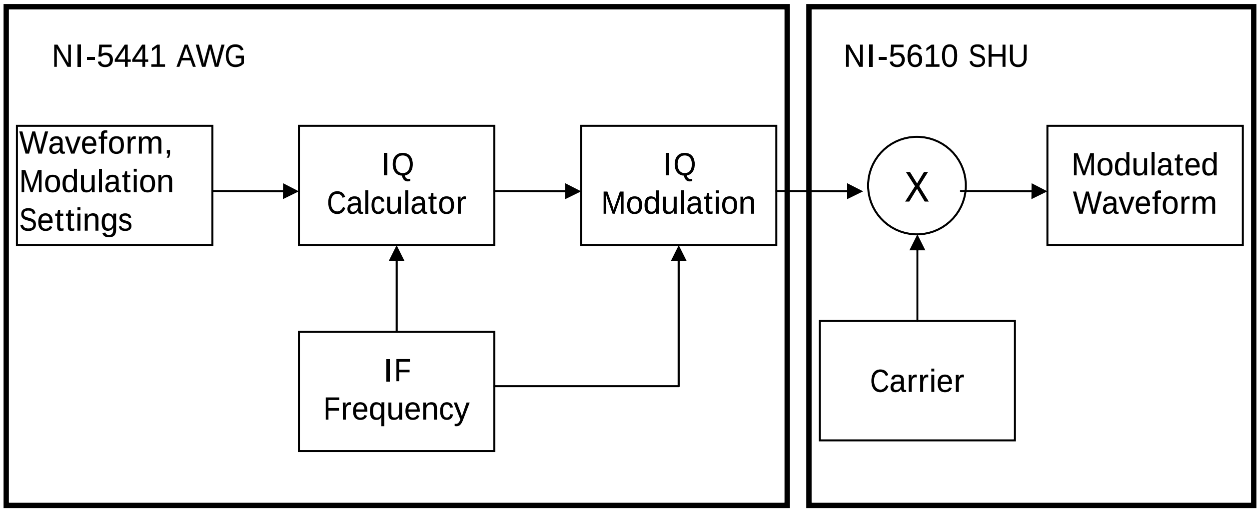

Figure 9-1: ni5671 Functional Block Diagram

The theory of operation of the ni5671 signal generator is explained in steps:

1. Satisfying the waveform and modulation settings provided by the user, the signal generator selects an intermediate frequency around which the waveform is generated.
2. The waveform and modulation settings and the IF clock are given as input to the IQ calculator. The IQ calculator will calculate the IQ values that are used to modulate the IF signal to generate the required waveform at IF.
3. According to the IQ values calculated by the IQ calculator, the IQ modulator will modulate the IF signal to generate the required arbitrary waveform at IF. More about IQ modulation is discussed in later chapters.
4. The IF waveform is converted to a continuous analog signal using digital to analog converters (DAC) not shown in the block diagram.
5. The continuous signal is passed into the super-heterodyne up-converter (SHU) where it is multiplied with the carrier frequency signal to up-convert it to the required frequency.

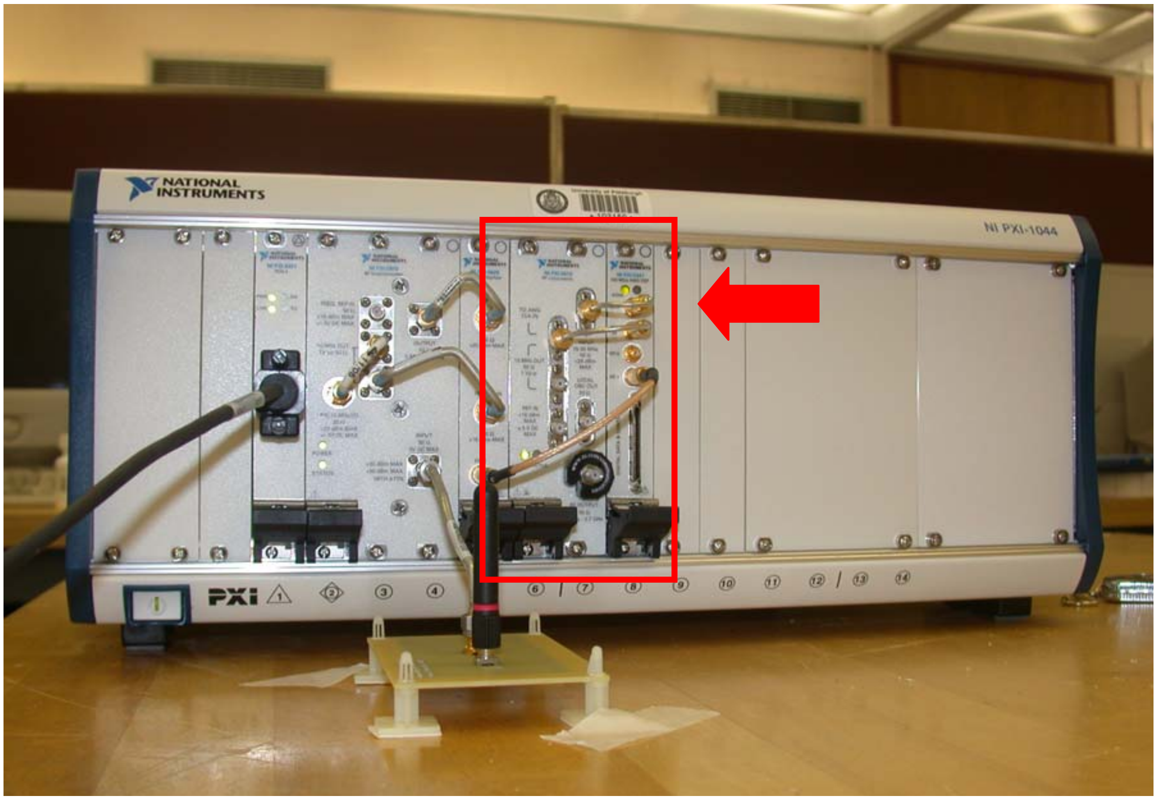

Figure 9-2: ni5441 + ni5610 = ni5671. Physical Connections

The physical connections between the AWG module and the SHU module are shown in Figure 9-2.

9.3 IQ MODULATION

The ni5671 RF signal generator generates arbitrary waveform using IQ modulation principle. It is possible to generate all modulation types using this modulation technique. The only block that would have to be replaced is the IQ calculator block in Figure 9-1.

Typically all commercial signal generators employ this technique to achieve the different modulation techniques that are supported by that RF signal generators. The IQ calculator is implemented using an FPGA (Field Programmable Gate Array). Depending upon the modulation technique selected by the user, the IQ calculator block is re-configured. This technique is very economical when the transmitter is expected to support more than one type of modulation.

Let the equation of a typical Sine Waveform is:

$A_c Cos(2\pi f_c t + \phi)$ - Equation 3-1.

where, A_c is the amplitude of the signal, f_c is the frequency and ϕ is the phase of the signal at time 't'.

All waveforms can be represented on the complex plane with the real component on the x-axis and the imaginary component on the y-axis. The waveform in Equation 3-1 can be represented on the complex plane as

$M(t)\angle\phi(t)$

where, $M(t)$ is the instantaneous amplitude of the signal at time 't' and $\phi(t)$ is the angle between the vector and the x-axis.

The representation of the waveform in Equation 3-1 on the complex plane is shown in Figure 9-3. The blue vector is the instantaneous value of sine waveform at time 't' with finite amplitude and angle with respect to x-axis.

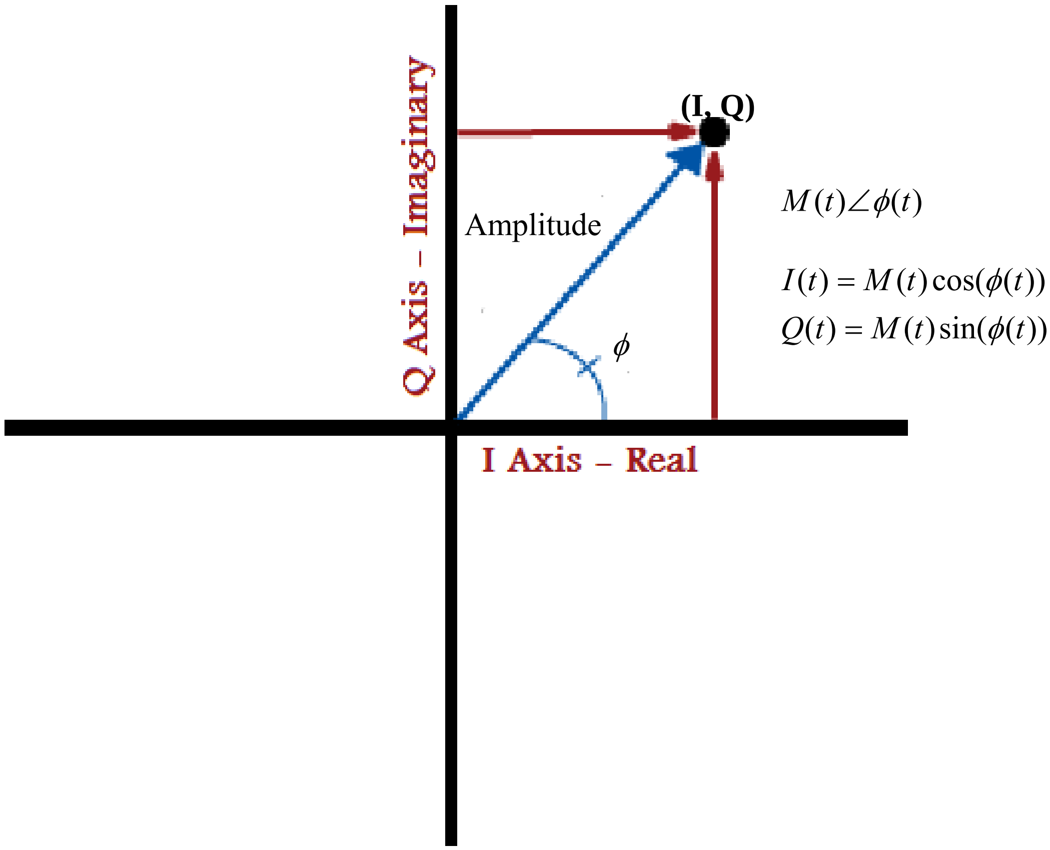

Figure 9-3: Representation of Instantaneous value of Sine Waveform

The M and ϕ is polar co-ordinate system can be converted into I and Q in rectangular co-ordinate system. In the rectangular system 'I' is the real part and 'Q' is the imaginary part.

$$M\angle\phi = I + iQ$$

Principle of IQ Modulation

It is possible to join a Sine Wave (10MHz) of higher frequency than the message signal sampled at different IQ (Amplitude and Phase) to form a continuous Sine Wave (2MHz) of *another frequency significantly lower than the higher frequency previously selected, amplitude or phase which is the message signal.*

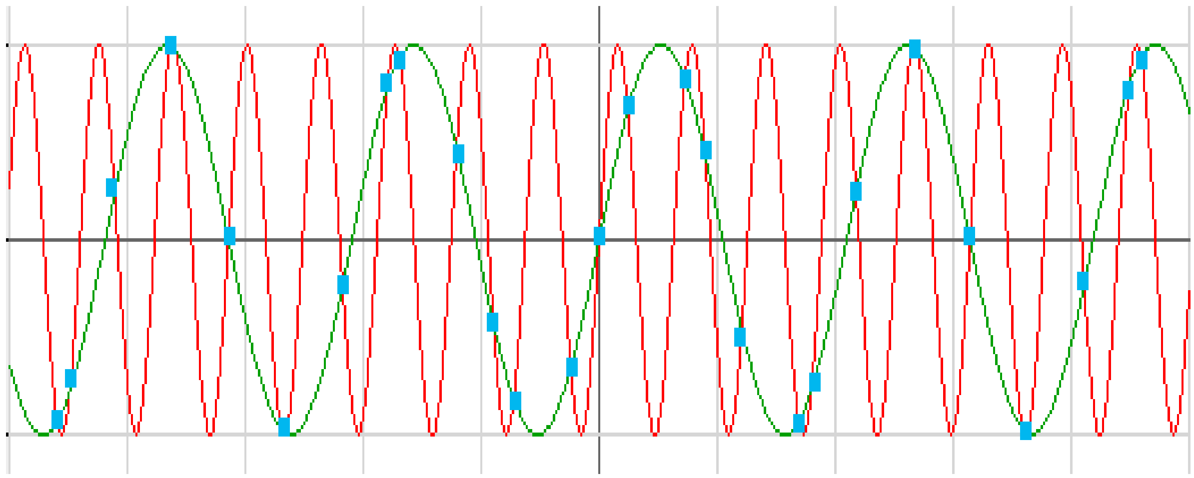

Figure 9-4: Principle of IQ Modulation

The block diagram of an IQ modulator is shown in Figure 9-5. The phase and angle data calculated by the IQ calculator is given as input to the IQ modulator. These data are converted into rectangular co-ordinates from polar co-ordinates. Depending upon the waveform and modulation settings provided by the user, an IF is selected between 15MHz – 35MHz. This IF signal is multiplied by the I data and the same IF delayed by 90 degrees is multiplied by the Q data. The resulting signals are passed through a subtraction circuit to generate the necessary waveform at IF.

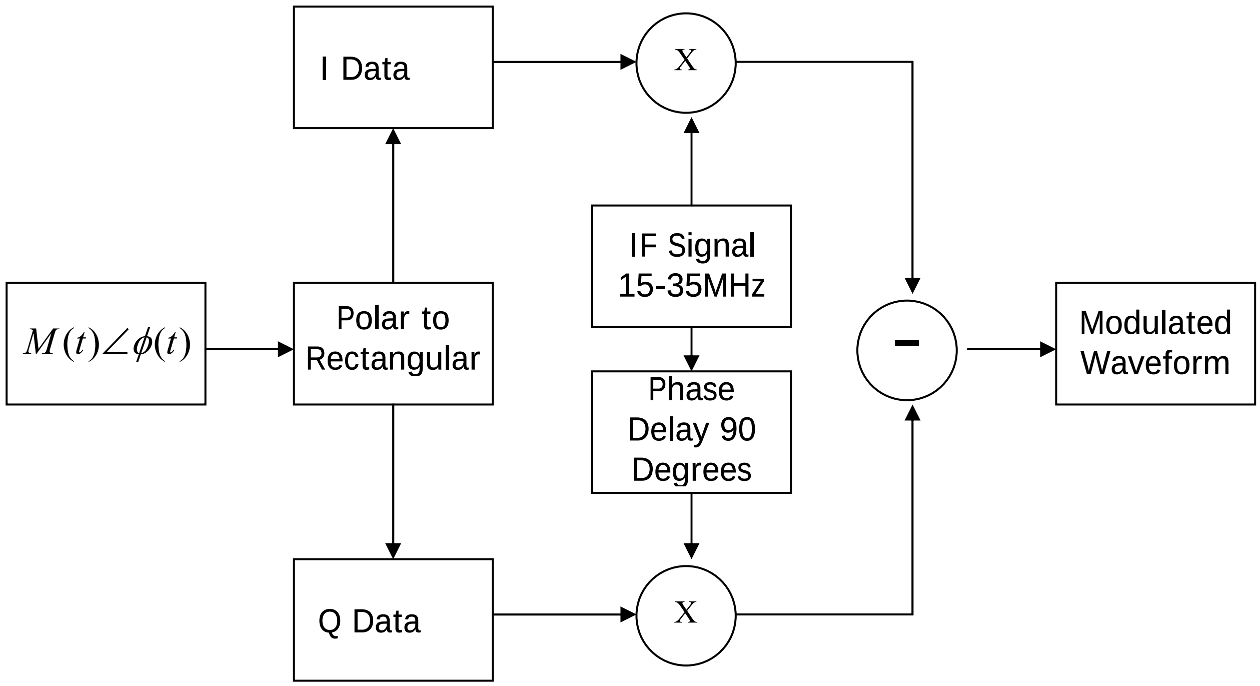

Figure 9-5: IQ Modulator Block Diagram

9.4 PHASE CONTINUOUS AND DISCONTINUOUS SIGNALS

Consider two signals, *Signal A* and *Signal B*, of different single tone frequencies that are IQ modulated by the ni5671 RFSG. The two signals can be modulated and then transmitted while configuring the RFSG in different modes of operation that are explained in following sections, but the concept of phase continuity and discontinuity apply to all modes and all signals transmitted from the ni5671 RFSG.

To further simplify the concept of phase continuity and discontinuity assume that the two signals are FM modulated using IQ modulation technique. For all FM modulated signals, the amplitude is constant (typically 1) and only the phase changes in the IQ data array (In $M\angle\phi$ M = 1 and ϕ changes).

The two signals are phase continuous if the phase of the last IQ sample of *Signal A* is equal to the phase of the first IQ sample of *Signal B* minus the phase difference between any two adjacent samples. Also a signal waveform is phase continuous if it contains an integer number of cycles of the IF signals that is sampled at different IQ to generate the necessary waveform.

The user-specified baseband IQ waveform written to the AWG module must be phase continuous, or a phase glitch appears in the RF output signal when the generation loops back to the beginning of the waveform. The NI-RFSG driver software up converts the provided baseband IQ signal to IF by multiplying it with a carrier. The IF waveform array will be phase continuous only if the array contains an integer number of cycles of the IF carrier frequency signals.

Figure 9-6 shows the difference in continuous and discontinuous sampling on the same sinusoidal signal.

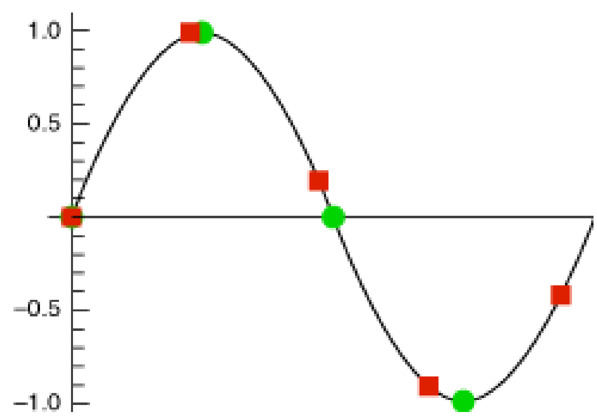

Figure 9-6: Waveform sampled at different sampling rates.
Sampling at green circles is phase continuous sampling.
Sampling at red squares is phase discontinuous sampling.

Summarizing the concept of continuous and discontinuous sampling, two waveforms can be transmitted one after the other with zero delay in between only if they satisfy the phase continuous condition explained. If two phase discontinuous signals are transmitted one after the other, the RFSG will require time to adjust itself and in this time the properties of the signal transmission are unpredictable and typically manifest themselves as an overshoot or undershoot between the two signals.

9.5 NI-RFSG PROGRAMMING STATE MODEL

The NI-RFSG programming model has three main states: Configuration (Idle), Committed, and Generation (Running). The programming state model shown in Figure 9-7 depicts the programming state model for the NI-RFSG hardware and software.

All session properties of the NI RFSG are programmed in the Configuration state. However, when in the Configuration state, the properties have not yet been applied to the hardware module. Therefore the module configuration may not match the session property values. The NI-RFSG device will not generate a signal in the Configuration state.

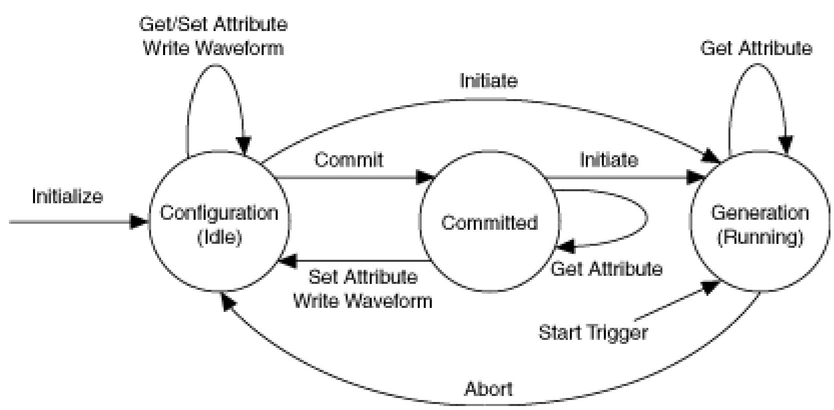

Figure 9-7: States of NI RFSG. Courtesy: NI

Calling the niRFSG commit function from the configuration state verifies all property settings, validates the specified configuration, configures the hardware modules to settings selected, writes the waveform to the AWG module onboard memory and finally transitions to the committed state. If any properties are changed while in the committed state, the session implicitly transitions back to the Configuration state and the hardware configuration reflects the previously committed properties.

In the Generation state, session properties always reflect the current state of the module, and the module is either waiting on a trigger or generating a signal.

9.6 CONFIGURING NI 5671

The NI – 5671 can only be configured using Labview. It has no buttons on the chassis for programming ability. Some of the important VIs used in configuring NI – 5671 are discussed below.

9.6.1 niRFSG Initialize

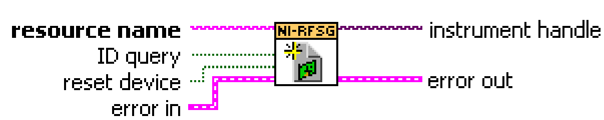

Figure 9-8: niRFSG Initialize

This VI performs the basic initialization actions. The VI creates a new instrument driver session. It opens a session to the device you specify as resource name. If the reset device option is set to TRUE, the VI will reset the device to a previous known state. The VI also returns an instrument handle that is used to identify the NI-RFSG device in all subsequent NI-RFSG VIs.

9.6.2 niRFSG Configure RF

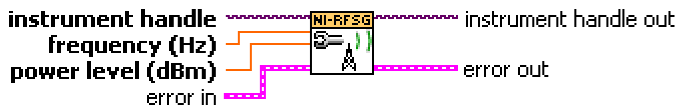

Figure 9-9: niRFSG configure RF

This VI will configure the frequency and also the power level of the RF output signal transmitted through the antenna attached to the RFSG. The RFSG device must be in the configuration state when this VI is executed.

9.6.3 niRFSG Configure Generation Mode

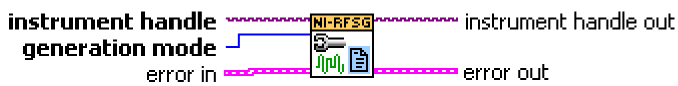

Figure 9-10: niRFSG Configure Generation Mode

This VI will configure the RFSG device to generate a continuous wave sine tone, apply IQ (vector) modulation to the RF output signal, or play arbitrary waveforms according to scripts. The RFSG device must be in the configuration state when this VI is executed. In programming the GOLD reader the scripts mode is used.

9.6.4 niRFSG Write Arb Waveform

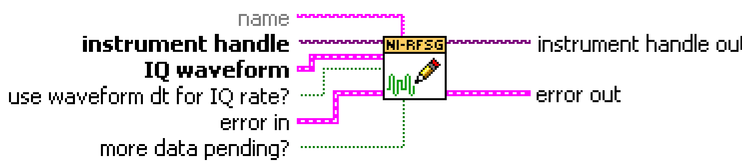

Figure 9-11: niRFSG Write Arb Waveform

This VI loads an arbitrary waveform to the RFSG device built in memory starting at the last written position and inputs the I and Q vectors of a complex baseband signal. In developing the GOLD standard, the pieces of the signal (1 preamble pulse, 1 data pulse etc.) are loaded into the RFSG. Scripts are developed to join the pieces together in the RFSG to transmit the signal according to the format specified in the standard (ISO 18000-7.2, 2008).

9.6.5 niRFSG Configure Signal Bandwidth

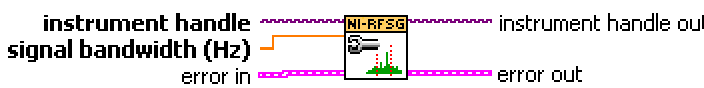

Figure 9-12: niRFSG Configure Signal BW

This VI will configure the signal bandwidth of the arbitrary waveform. The NI-RFSG device must be in the configuration state before this VI is executed.

9.6.6 niRFSG Write Script

Figure 9-13: niRFSG write script

This VI will specify a string containing a script that controls waveform generation in script mode. The script will call the pieces of signal loaded into the memory of the RFSG and join them together.

9.6.7 niRFSG Select Arb Waveform

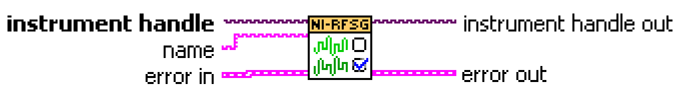

Figure 9-14: ni5671 Select Arb Script

If the signal generator is configured in *Arb Waveform* mode, then this VI is used select a particular waveform from a set of waveforms already uploaded into the RFSG memory. The selected waveform is then transmitted once. To transmit another waveform, the same VI is used to select the required waveform and the entire process is repeated again.

9.6.8 niRFSG Initiate

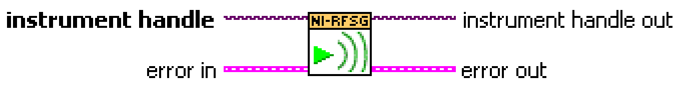

Figure 9-15: niRFSG write script

This VI will initiate signal generation, causing the NI-RFSG device to leave the configuration or committed state and enter the generation state. The operation returns when the RF output signal is settled.

9.6.9 niRFSG Check Generation Status

Figure 9-16: niRFSG Configure Signal BW

This VI will check the status of the signal generation by the RFSG. This VI is used to check for any errors that may occur during signal generation, or to check whether the device is finished generating the desired signal.

9.6.10 niRFSG Configure Output Enabled

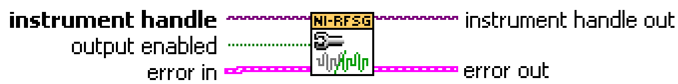

Figure 9-17: niRFSG Configure output enabled

This VI enables or disables signal output can be called in any software state, and it does not change the current state. Setting output enabled to FALSE while in the Signal Generation state stops signal output although generation continues internally.

9.6.11 niRFSG Close

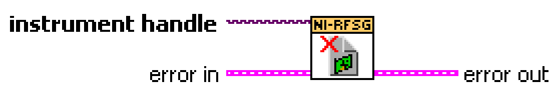

Figure 9-18: niRFSG close

This VI will close the RFSG. After initializing the VI, it should be always closed using this VI. This VI aborts any signal generation in progress, terminates the instrument I/O session, destroys the instrument driver session and any set properties and de-allocates any memory resources used by NI-RFSG.

The VIs discussed in Section 9.6 are to configure the arbitrary waveform module and the up-converter module. This is not necessary, but a preferred and simple procedure to get started. The waveform modulate and the up-converter module can be configured separately one after the other using VIs provided by NI or by developing new VIs. Also the modules can be configured using GPIB command scripts that can be found in the RFSG programmer's manual. The GPIB scripts can be parsed and the commands can be transmitted to the hardware devices through the PXI bus using the GPIB configuration module present in LabView software package. It is up to the experience of the programmer to develop ingenious procedures to program the signal generator pushing it to its limits.

9.7 MODES OF TRANSMISSION IN NI5671 RFSG

The ni5671 RFSG can be operated in three modes of operation. Understanding the variations among these modes of operation, though appearing insignificant, will help in exploiting the features in each of the modes stretching the operation of the RFSG to its limits and in other cases accept the limits of operation.

The three modes of operation are:

1. Script Mode
2. Arbitrary Waveform Mode
3. Continuous Mode

The description of the different modes of operation, the advantages and disadvantages of each of the modes for ni5671 RFSG with respect to the current application is discussed.

9.7.1 Continuous Wave Mode

In this mode of transmission, a single tone or multi tone modulated waveform is loaded into the memory of the ni5671 RFSG. This signal is transmitted continuously repeating itself. The advantage of this mode is that waveforms that are repetitive in nature for long durations (example the wakeup or co-header testing in this dissertation) can be transmitted with high sampling rates. This makes it possible to vary the pulse width of the waveform by 10ns and the memory requirement is not huge as only a portion of the signal is loaded into the RFSG memory and transmission is repeated. The disadvantage of this mode is that the time duration of transmission cannot be controlled accurately (example exactly 2.4 seconds of wakeup) as the transmission time is calculated and modified in software. The second disadvantage with this mode is that it is not possible to transmit two waveforms with zero delay between them (example wakeup and co-header with zero delay between them) as additional time is required to clear memory of existing waveform and load the new waveform and start transmission again.

9.7.2 Arbitrary Waveform Mode

In this mode of transmission, different modulated waveforms can be loaded into memory before transmission. Each waveform is given a name and address location in memory. During transmission, the required waveform can be selected by its name and transmitted. The advantage of this mode is that the time required between successive waveform transmissions is greatly reduced and the sampling rates can be very high. The pulse widths of the waveform can be varied by 10ns. The disadvantages of this mode are, though the time between successive waveforms is reduced when compared to CW mode, the delay is greater than zero (wakeup and co-header cannot be transmitted with zero delay). The other disadvantage is the memory requirement. Long signals have to be completely loaded into the RFSG before transmission as continuous repetition of same signal is not allowed which requires huge amounts of memory (the complete wakeup signal cannot be loaded into the RFSG).

9.7.3 Script Mode

In this mode of transmission, different modulated waveforms can be loaded into memory before transmission. Each waveform is given a name and address location in memory. After loading the different waveforms into memory a script can be written to describe the order of transmission of different signals, the delays in-between them and also the number of times each waveform has to be repeated. The advantage of this mode is that the time delay between transmissions of two different signals is zero. Continuous repetition of signals is allowed and hence there is no memory limitation for transmitting long signals. Signals can be sampled at high IQ rates. This makes it possible to vary the pulse widths by 10ns. The only disadvantage of this method is that the programmer must ensure that the different signals that are to be transmitted in succession are phase continuous. To make sure that the different signals are phase continuous, the IQ sampling rates of the signals have to adjusted and some times this can limit the maximum sampling rate of the signals increasing the minimum change in pulse width that can be changed (pulse width of wakeup and co-header can be varied by 200ns not 10ns).

10.0 INTEROPERABILITY TEST METHODOLOGY

Having understood the persisting problems with interoperability among active RFID in section 4.1, the limitations of the traditional test approach, its inability to elaborate or focus on the reasons pertaining to the lack of interoperability in section 4.2 and the statistical concepts in sections 6.3 and 6.8, this chapter is devoted to introduce and construe the interoperability test methodology and procedure for verification of the interoperability property among active RFID systems.

The first step in developing the interoperability test methodology is to understand the ISO 18000-7 standard, as most active RFID systems are designed according to the specifications drafted in this standard. The different signal parameters and timing constraints in the physical layer of the RFID system that will affect interoperability must be documented. These are called the *factors* affecting interoperability. All the factors affecting interoperability cannot be derived from the standard itself. Some of the factors are not explicitly defined by the standard and can only be discovered by extensive practical application of different RFID systems or stimulating a particular RFID system with a constant and transparent reference system. These factors that affect the interoperability property of an RFID system and not defined by the standard are termed as the “grey areas” of the standard. The ISO 18000-7 standard is relatively young standard in its early stages of development. The development of this interoperability test methodology and its realization will help elucidate the current areas of the standard that are ambiguous. The ISO 18000-7 standard has been chosen in this dissertation as an example to demonstrate the practicality of the research. The methodology in this chapter will apply to similar standards.

After the entire list of factors affecting interoperability is documented the next step is to separate the realizable factors (significant factors for practical implementation) from the nuisance and uncontrollable factors. From the entire list of factors that are enumerated after the intensive and iterative research, it has to be perceived that all the factors are not realizable in the experiment setup to test interoperability. The current commercial hardware (RF Signal Generators) available and the interaction among certain groups of factors that cannot be eradicated (Bandwidth factor from FSK deviation factor as Bandwidth = Max Deviation – Min Deviation) will abstract the uncontrollable and nuisance factors from the absolute list of factors leaving the realizable factors.

Assume that all factors are discrete in value and hence the possible values for each of the above realizable factors affecting interoperability is a finite set of elements. The experiment to test for interoperability, when designed as a complete regression test, will test all possible values of one factor with all possible values of remaining factors. This time of experimentation can be reduced if initial analysis is performed on the factors to determine and distinguish dependent factors from independent factors, making sub-groups of the realizable factors. This separation of dependent factors from independent factors can be performed using analysis of variance technique. Purposeful changes are made to the value of one factor and the range of values for all other factors for which the system (in this case the active tag) functions as expected is tabulated. The analysis of variance technique is employed on the tabulated data to determine if the purposeful change in one factor produces a significant change in the valid range of another factor. If the change in the valid range of a factor is significantly influence by the purposeful change in the current factor, then the two factors can be concluded as dependent. If the change is not significant, then the two factors are independent. In the interoperability experiments with the tag, the values of the independent factor can be varied maintaining all other factors at their nominal values thus reducing the time of the interoperability experiment considerably.

Until now, all the factors affecting interoperability are considered to be discrete. On the contrary, among all the realizable factors, only few of them are discrete in value while most of them accept a range of inputs on the real number line, enlarging the possible values to a set of infinite items. In practice it is not possible to test a certain factor for all possible number on the real number line bounded by two real numbers. Such an experiment would provide results with an ideal 100% confidence which in practice cannot physically be achieved. From the infinite possible values, a finite number of values (or samples) must be tested with certain degree of confidence (< 100%). The results of the experiment on these few samples can be assumed to hold true to all remaining possible values of the factor. This technique of testing few samples from a huge lot to comment upon the entire lot is called the acceptance sampling technique. Using the Accept on Zero sampling technique, the number of test values of the factors, which is an infinite set of real numbers, is made finite.

Within the realizable factors, from experience, it can be stated that certain factors are very clearly defined by the standard and there is very little possibility of someone misinterpreting and incorrectly implementing those factor, while the possibility of misconstruing certain factors is high. Understanding the level of contortion in implementation of the factors can introduce weighting into the experiment, testing the factors more prone to errors more intensively while being comparatively lenient but thorough in testing factors that are rarely prone to errors. This will help reduce the time of the experiment and also increases the capability of the test to discover the defects in the system hindering interoperability. This variation in the number of samples tested for different factors can be achieved by varying the corresponding LTPD value from the nominal value selected by the user. The single LTPD value entered while selecting a sampling plan can be denoted as “Normalized LTPD”. This normalized LTPD value can be mapped to individual LTPD values for corresponding factors using functions depending upon overall conformance test results of different active RFID tags. The mapping of LTPD of factors with insufficient test samples for required level of confidence due to hardware limitations is also considered and implemented during the normalization process.

The sample of items from each factor is tested by transmitting commands from the GOLD reference reader altering signal parameters of each factor and observing the response from the tag under test. The error in interoperability property of the factor is declared satisfactory if tag behaves as expected for commands with that factor at all samples. If the tag deviates from the expected behavior for one or more samples, the error in interoperability property of the factor is not satisfactory. If the error in interoperability in all factors is satisfactory then the tag is declared interoperable.

The test procedure and analysis described is independent of the hardware and software modules that can be used to realize it. In such a situation it should be possible to compare tests performed on the same hardware or on different hardware. The comparison is valid only if the same mapping functions are used to normalize the LTPD (or no normalization scheme is used as agreed by both parties) and one of the parameters is held constant in the sampling plan (either β is constant or LTPD is constant). It is common practice to hold β constant. In such a scenario, the LTPD of each factor is compared. The test setup with lower LTPD is better. It needs to be noted that each factor has to be compared separately.

The methodology discussed is implemented as an automated experiment in Labview software, where with minimum human supervision and direction, the commands are transmitted from a reference reader, with changes in every factor over its entire possible range as defined by the standard. The response from the commercial tag (devise under test – DUT) is recorded and analyzed to verify that the response is as expected. If the tag responds as expected to all possible variations in the command without violating the standard, then it can be concluded with a confidence (< 100%) that the tag will work with all commercial readers available and so it is interoperable.

The steps involved in the development of the interoperability test methodology introduced here are explained in detail with circumstantial examples in subsequent sections.

10.1 METHODOLOGY – BLOCK DIAGRAM REPRESENTATION

The implementation of the methodology that is proposed to test interoperability of an active RFID system by designing an experiment in LabView software is depicted in Figure 10-1, to give the reader a broad picture of an overall concept. The figure can be considered as a black box view of the experiment or the software package. The inputs (which will be defined shortly) to this experiment are the normalized LTPD and β (beta) and the range within which each of the factors should be tested. The LTPD and β values together constitute an acceptance sampling plan (AoZ Plan).

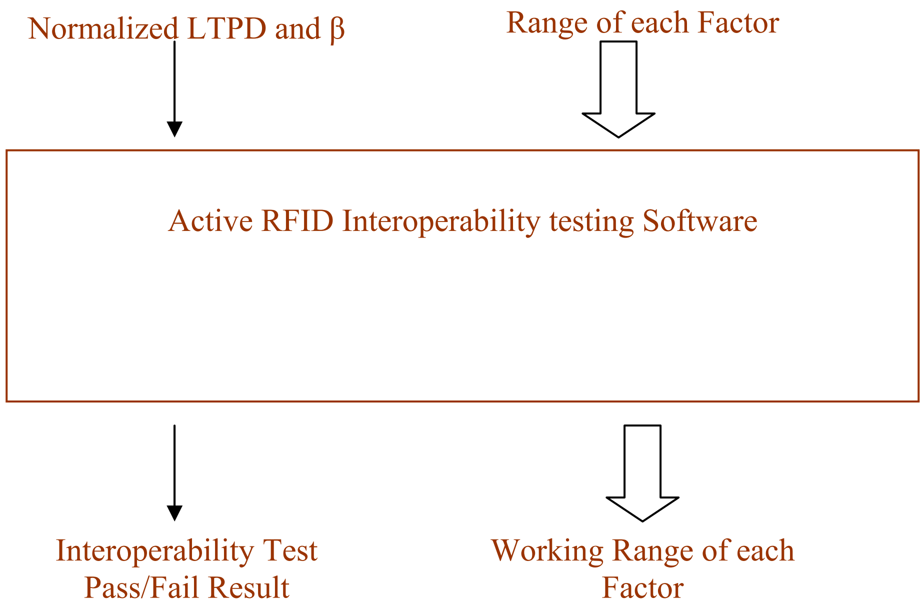

Figure 10-1: Black Box view of Interoperability Test Software package

The normalized LTPD value is the measure of the intensity of the test (number of samples within each factor's range that will be tested). Decreasing the normalized LTPD entered into the software (keeping β constant) will make the test more intense, testing more samples of each factor. Increasing the normalized AQL entered into the software (keeping β constant) will make the test somewhat lenient. This variability among factors is proposed to allow previous testing results to be incorporated as information that appears to be relevant to solving the problem. The typical value or the nominal for the range of each factor is the range of values defined by the ISO 18000-7 standard. It is also possible to test the RFID system for interoperability beyond the range described by the standard or to test it within the range described by the standard.

The outputs of the software package include the Pass or Fail result of the test (Interoperable or Not Interoperable) and also the range of values for each factor which the RFID system accepts.

Having understood the inputs and outputs (black box view) of the interoperability test software, the next step is to understand the flow of data and the methodology within the test software.

Figure 10-2 displays the detailed data flow diagram of the Interoperability testing software. The analysis of variance technique is used to separate dependent and independent factors before developing the experiment.

As explained above, the inputs to this software are the normalized LTPD, β and the range within which each of the factors should be tested. From the normalized LTPD value entered, the LTPD of each individual factor is calculated which determines the number of samples of each factor to be tested. This is the normalization of LTPD process that introduces weighting into the interoperability test. This is because some factors are more error prone than others and hardware limitations restrict the sample size in few factors. The factors which are more prone to errors should be more intensively tested (taking more samples within the range) than factors less prone to errors. This measure of which factors need to be more intensively tested will be decided upon the results of conformance tests. The techniques used to calculate the LTPD of individual factors which in turn will decide the number of samples to be tested is explained in section 10.6. It has to be noted that the normalized LTPD value and the corresponding individual LTPD values calculated are measures of the quality of the test of each factor but not the quality of the RFID system as a whole.

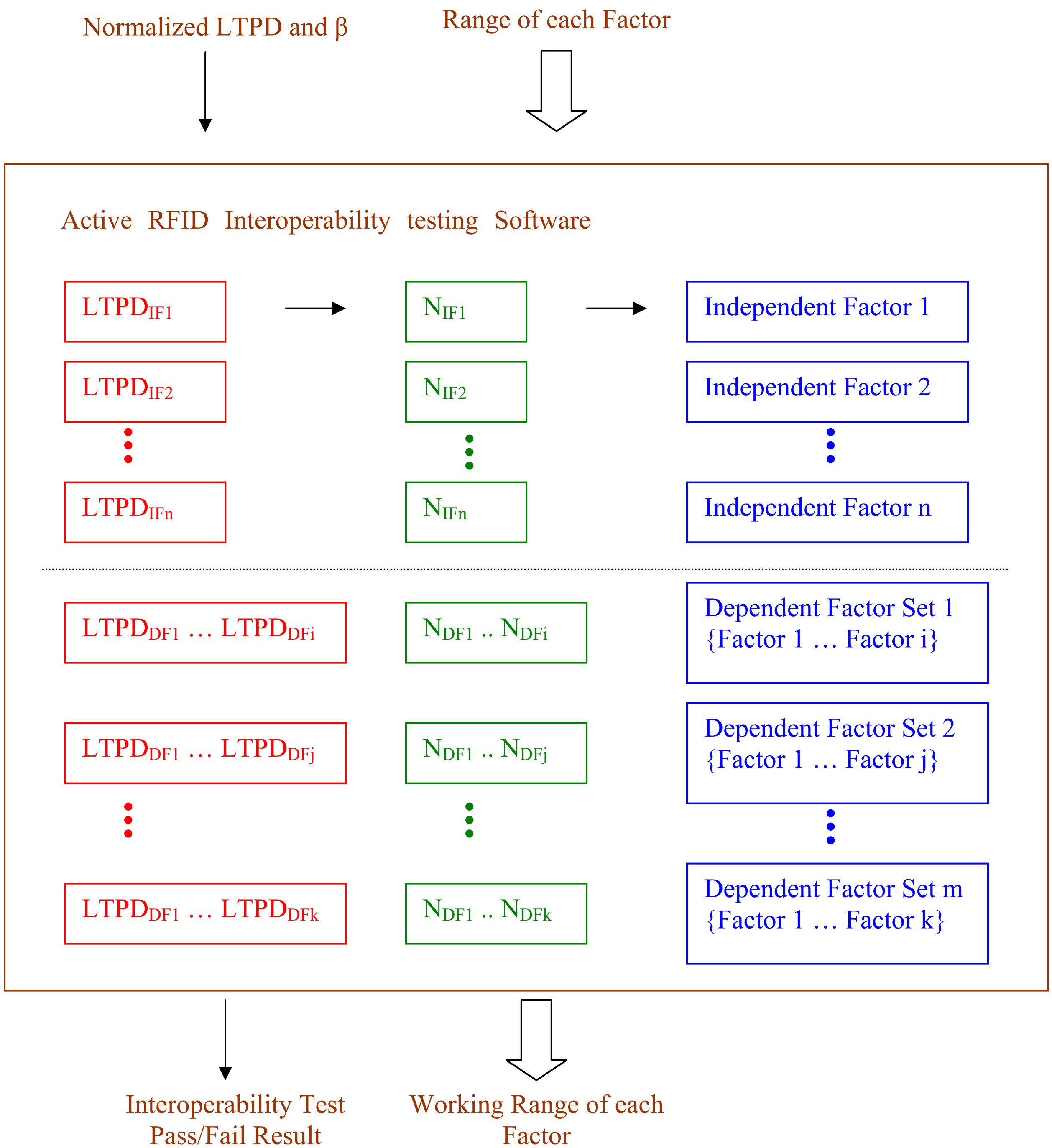

Figure 10-2: Data Flow Model of Interoperability Test Software

IF = Independent Factor; DF = Dependent Factor; N = No. of Samples

$LTPD_{subscript}$ = f(Normalized LTPD); $N_{subscript}$ = g($LTPD_{subscript}$); where f & g are functions

After calculating the number of samples within the range of each factor to be tested, it is still not feasible to test every possible value of each factor with every possible value of all other factors (100% regression analysis). The time to realize such a test would be unrealistic. The solution to this problem is to analyze if the factors (variants) are dependent or independent. Suppose there are valid values a1, a2 for factor 'A' and valid values b1, b2 for factor 'B'; dependent-independent analysis will determine if there is a possibility that the system may not accept the combination of {a2,b2}, after it accepts the combination of {a1,b2}, {a2,b1} and {a1,b1}. All independent factors can be tested separately and dependent sets of factors can be tested separately speeding up the testing process. The ANOVA technique used to separate dependent and independent factors is discussed in section 10.4.

10.1.1 Flow of Data in Test

Summary of the data flow in the block diagram is explained in steps:

1. Separate dependent and independent factors using AVOVA technique. [Section 10.4]
2. Calculate individual LTPD from normalized LTPD value entered. [Section 10.6]
3. Calculate corresponding N value (samples to test) for each factor. [Section 10.5]
4. Verify that RFID system accepts values of each factor to determine interoperability and working range of each factor. [Section 4.1 & Section 11.0]

10.2 FACTORS INFLUENCING RFID SYSTEM OPERATION

A factor can be defined as an input variable to an experiment which when varied will alter the result of the experiment [9].

This alteration in the result due to variation of a factor can be positive and encouraging to the experimenter or it can be discouraging. A thorough analysis of numerous active RFID systems and the ISO 18000-7 standard has been performed. Table 10-1 below lists all factors that will influence the interoperability of an RFID system that have been identified to this point, both from practical observations and theoretical reasoning. These factors are recorded after analyzing three candidate RFID systems from different vendors and the GOLD standard RFID system developed by University of Pittsburgh. The GOLD standard reader is the NI signal generator (ni5671) which is programmed in LabView 8.2 to emulate a fully conforming reader. The GOLD standard tag is the R&S signal generator (SMJ100A) combined with the real time command detector circuit.

Table 10-1: All Factors influencing interoperability

S.No	Factor Name
1	Symbol low frequency deviation
2	Symbol high frequency deviation
3	Average symbol low frequency deviation (Pulse)
4	Average symbol high frequency deviation (Pulse)
5	Transition Time
6	Bandwidth
7	Carrier
8	Number of preamble pulses
9	Symbol low preamble width
10	Symbol high preamble width
11	Preamble width (Low + High)
12	Symbol low sync pulse width
13	Symbol high sync pulse width
14	Preamble Length

Table 10.1 (continued)

15	Data symbol low width
16	Data symbol high width
17	Data width (Low + High)
18	Average Data symbol low width
19	Average Data symbol high width
20	Average Data width (Low + High)
21	Data rate
22	End pulse length
23	Wake up symbol low width
24	Wake up symbol high width
25	Wake up width (Low + High)
26	Average Wake up symbol low width
27	Average Wake up symbol high width
28	Average Wake up width (Low + High)
29	Wake up length
30	Wake up rate
31	Co-header symbol low width
32	Co-header symbol high width
33	Co-header width (Low + High)
34	Average Co-header symbol low width
35	Average Co-header symbol high width
36	Average Co-header width (Low + High)
37	Co-header length
38	Co-header rate
39	Time between wake up and co-header

Table 10.1 (continued)

40	Time between Start of wake up to End of co-header
41	Time between end of wake up to start of command preamble
42	Time Tag is awake after wakeup
43	Initialization Pulse
44	Termination Pulse
45	Commands and Responses Supported

Additional factors when designing the GOLD programmable tag are slot number, start time within slot, end time within slot and guard time. It is unclear at this point if these factors can be considered within the physical communication layer.

Some of the factors mentioned in Table 10-1 are not directly controllable due to hardware limitations and some being average values of the controllable factors. Therefore to make the experiment effective, the nuisance factors and uncontrollable factors are separated, and the concept of blocking will be used.

10.3 SELECTION OF REALIZABLE FACTORS

Blocking is a technique where an experiment is performed with only a few factors chosen out of the entire factor set [9].

The factors in each block will depend on different situations and the desired output. For example all potential design factors can be blocked into a single experiment.

The first step for blocking is to separate the potential design factors and the nuisance factors from the entire set of factors. For this the 44 factors mentioned in Table 10-1 are separated into 4 blocks. This primary blocking is shown in Table 10-2.

Table 10-2: Blocking of Factors

Factor Name	Block
Symbol low frequency deviation	1
Symbol high frequency deviation	1
Average symbol low frequency deviation (Pulse)	2
Average symbol high frequency deviation (Pulse)	2
Transition Time	1
Bandwidth	2
Carrier	1
Number of preamble pulses	3
Symbol low preamble width	1
Symbol high preamble width	1
Preamble width	2
Symbol low sync pulse width	1
Symbol high sync pulse width	1
Preamble Length	2
Data symbol low width	1
Data symbol high width	1
Data width	1
Average Data symbol low width	2
Average Data symbol high width	2
Average Data width	2
Data rate	2
End pulse length	3
Wake up symbol low width	1

Table 10-2 (continued)

Wake up symbol high width	1
Wake up width	1
Average Wake up symbol low width	2
Average Wake up symbol high width	2
Average Wake up width	2
Wake up length	3
Wake up rate	2
Co-header symbol low width	1
Co-header symbol high width	1
Co-header width	1
Average Co-header symbol low width	2
Average Co-header symbol high width	2
Average Co-header width	2
Co-header length	3
Co-header rate	2
Time between wake up and co-header	4
Time between Start of wake up to End of co-header	4
Time between end of wake up sequence to start of command preamble	4
Time Tag is awake after wakeup	3
Symbol before first preamble	4
Commands and Responses supported	1

Minimizing the number of factors will make the experiment very robust and efficient. Factors in block 1 are those mentioned in the standard and by careful previous analysis, these factors are found to be crucial for interoperability.

Factors in block 2 are also mentioned in the standard but these factors are calculated based upon values of factors in block 1. For example, average data pulse width of all data pulses in the signal will be in block 2 and data pulse width will be in block 1. Bandwidth of the signal is dependent on FSK deviation of the signal (BW = Max. FSK Deviation – Min. FSK Deviation) and hence it is in block 2. The band width of the signal cannot be altered without changing the FSK Deviation parameters. The factors in block 2 can be considered as uncontrollable factors though this is not completely true as will be explained.

Factors in block 3 are those mentioned in the standard, but from initial research it was found that the tags will work even if these conditions are not met. Though not meeting the requirement for these factors as specified by the standard is a direct violation of the standard, it does not directly affect the interoperability property of the RFID system. These factors will be considered in the interoperability experiment but are still mentioned here only to publish the results of the research.

Finally factors in block 4 are those not mentioned in the standard. These factors were discovered at the University of Pittsburgh by careful analysis of different candidate RFID systems. In the past, these factors have constituted "gray areas" [2],[5] requiring for their investigation by the standard groups. In addition to interoperability confidence levels, this research will help identify such issues for early resolution through speeding up the standards process.

Finally, the factors in Table 10-3 will be considered to determine the interoperability of a particular RFID system. There are total of 18 different realizable factors.

Table 10-3: Final List of Factors

Factor Name
Symbol frequency deviation
Carrier
Number of preamble pulses
Preamble width
Sync pulse width
Data pulse width
End pulse length
Wake up pulse width
Wake up length
Co-header pulse width
Co-header length
Time between wake up and co-header
Time between end of wake up sequence to start of command preamble
Time Tag is awake after wakeup
Initialization Pulse
Termination Pulse
Transition Time
Commands and Responses supported

Due to hardware limitations, the symbol Low and symbol High frequency deviation factors cannot be controlled separately. Hence they are combined for the sake of the experiment into symbol frequency deviation factor. Similarly, the low and high pulse widths cannot be controlled separately and hence are combined together for the sake of realizing the experiment. The resolution or the minimum change in each of the factors mentioned in

Table 10-3 is tabulated in Table 10-4. The resolution of factors with similar properties (wakeup pulse width, co-header pulse width and data pulse width) is not equal due to different frequency components in the communication sequence (wakeup, co-header and command) requiring different intermediate frequency signals to perform the IQ modulation and the duration of the different signals requiring different modes of transmission using the RF signal generator. This is explained in section 9.3 about IQ modulation in RF signal generators.

Table 10-4: Factor and their Resolution

Factor Name	Resolution
Symbol frequency deviation	1kHz
Carrier	1kHz
Number of preamble pulses	1
Preamble width	10ns
Sync pulse width	10ns
Data pulse width	10ns
End pulse length	10ns
Wake up pulse width	200ns
Wake up length	32us
Co-header pulse width	200ns
Co-header length	100us
Time between wake up and co-header	200ns
Time between end of wake up sequence to start of command preamble	1ms

Table 10-4 (continued)

Time Tag is awake after wakeup	1ms
Initialization Pulse	10ns
Termination Pulse	10ns
Commands and Responses supported	All Possible
Transition Time	Discrete Ranges

Table 10-5 shows the realizable factors and their nominal values as defined by the ISO 18000-7 standard.

Table 10-5: Realizable factors and their nominal values

Factor Name	**Nominal Value**
Symbol frequency deviation	50kHz
Carrier	433.92MHz
Number of preamble pulses	20
Preamble width	60us
Sync pulse width	108us
Data pulse width	36us
End pulse length	36us
Wake up pulse width	32us

Table 10-5 (continued)

Wake up length	2.4s
Co-header pulse width	100us
Co-header length	100ms
Time between wake up and co-header	Not well defined
Time between end of wake up sequence to start of command preamble	Unspecified
Time Tag is awake after wakeup	30s
Initialization Pulse	15us
Termination Pulse	15us
Commands and Responses supported	All Possible
Transition Time	<4us

10.4 SEPARATION OF DEPENDENT & INDEPENDENT FACTORS

The analysis of variance (ANOVA) technique that is described in detail in section 6.1 is used in the interoperability test methodology. This analysis is performed on the entire list of realizable factors before designing the experiment.

The analysis of variance will help analyze the effect of varying one factor on the working range of another factor. In this section, the ANOVA technique (Analysis of Variance) is utilized to establish the dependencies between two factors if any to separate the dependent factors from independent factors. The outcome of this monotonous exercise, performed before setting up the interoperability experiment, is that all independent factors can be tested using individual experiments rather than combining all 18 realizable factors in one experiment saving the iterations required in the experiment and thus speeding up the interoperability determination process. When testing the working range of an independent factor, the remaining factors are constant at their nominal values. One or more experiments consisting of groups of dependent factors will test the remaining dependent factors.

The effect of varying carrier frequency on the maximum FSK deviation limit is analyzed as an example. Similarly the effect of varying data pulse width on the maximum FSK deviation limit is analyzed. From the resulting analysis of variance tables of the two experiments, the factor, which has a significant influence on maximum FSK deviation limit, is calculated. Continuing the same analysis on all possible combinations of two realizable factors at once will separate dependent from independent factors.

10.4.1 Analysis of Variance – Carrier Accuracy vs. FSK Deviation

This experiment will record the changes in the FSK deviation as the carrier accuracy is varied. The first step is to calculate the boundary values of the carrier accuracy factor that will be varied in the ANOVA test. All the realizable factors including the carrier accuracy factor are programmed at their nominal value and the command is transmitted to the tag. The tag should respond to this command to proceed further with the test. The value of the carrier accuracy factor is varied to cover the entire range that is specified in the ISO 18000-7 standard. The value of the factor is further increased and decreased beyond the standard specified values until the tag responds to the transmitted command with all remaining factors at their nominal values. This range of values for which the tag successfully responds is the boundary values of the carrier accuracy factor for determining what factors interact with this factor using ANOVA. For different values between the boundary values previously determined, the maximum FSK deviation that the tag will accept is recorded. Similarly, for the different values between the boundary values previously determined, the minimum FSK deviation that the tag will accept is recorded. To calculate the maximum or minimum FSK deviation the tag can accept at particular carrier accuracy, the command is transmitted at that particular carrier and FSK deviation starting from the nominal value is increased/decreased from the nominal value to record the maximum/minimum FSK deviation. The analysis of variance is performed on the recorded data, i.e., carrier accuracy vs. maximum FSK deviation and carrier accuracy vs. minimum FSK deviation. From the analysis, if carrier accuracy is independent of both maximum and minimum FSK deviation then the two factors (carrier accuracy and FSK deviation) are independent. If otherwise, they are dependent.

To calculate the boundary values of carrier accuracy, all factors are programmed at the standard specified nominal values and the carrier accuracy factor is varied. The value for which the tag responds and does not respond is shown in Table 10-6.

Table 10-6: Carrier Accuracy Boundary Values

Carrier Accuracy (MHz)	Tag Responded
433.87	No
433.88	Yes
433.89	Yes
433.90	Yes
433.91	Yes
433.92	Yes
433.93	Yes
433.94	Yes
433.95	No

From the table the boundary values for the carrier accuracy is selected as 433.88 MHz to 433.94 MHz. This range includes the limits as specified by the standard.

The next step is to record the maximum FSK deviation accepted by the tag at each of these carrier values. Table 10-7 shows the FSK deviations accepted and rejected by the tag at one carrier value - 433.92 MHz, as an example.

Table 10-7: FSK Deviation accepted by Tag at 433.92MHz Carrier

Maximum FSK Deviation (kHz)	Tag Responded
50	Yes
55	Yes
60	Yes
65	Yes
70	Yes
75	Yes
80	Yes
85	No
90	No

From the above table the maximum FSK deviation accepted by tag at 433.92 MHz is 80 kHz. This experiment is repeated four times at each value of carrier for different carrier values between the boundary values. This data are shown in Table 10-8.

Table 10-8: Carrier Accuracy vs Maximum FSK Deviation Results

	Max. FSK Deviation (kHz)			
Carrier Frequency (MHz)	1	2	3	4
433.88	90	85	90	90
433.89	95	95	90	90
433.90	100	100	100	95
433.91	95	90	90	95
433.92	80	80	80	80
433.93	70	70	70	70
433.94	60	65	60	60

The analysis of variance between carrier accuracy and maximum FSK deviation is tabulated in Table 10-9 and Table 10-10 (df = Degrees of Freedom).

Table 10-9: Carrier Accuracy vs Maximum FSK Deviation Sum and Average Table

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	355	88.75	6.25
Row 2	4	370	92.5	8.3333
Row 3	4	395	98.75	6.25
Row 4	4	370	92.5	8.3333
Row 5	4	320	80	0
Row 6	4	280	70	0
Row 7	4	245	61.25	6.25

Table 10-10: Carrier Accuracy vs Maximum FSK Deviation ANOVA SUMMARY

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4446.429	6	741.0714	146.4706	5.04E-16	2.572712
Within Groups	106.25	21	5.059524			
Total	4552.679	27				

From the table it can be seen that the practically calculated F-value is significantly greater that the theoretical F-value.

F – Practical = 146.4 >> F – Theoretical = 2.57

Therefore carrier accuracy factor and maximum FSK deviation factor are dependent. This implies that carrier accuracy and FSK deviation are dependent even if carrier accuracy and minimum FSK deviation are independent. But to strengthen the result, the analysis is continued.

The minimum FSK deviation accepted by the tag at different carrier values is shown in Table 10-11.

Table 10-11: Carrier Accuracy vs Minimum FSK Deviation Results

	Min. FSK Deviation			
Carrier Frequency (MHz)	1	2	3	4
433.88	20	20	25	20
433.89	15	15	15	15
433.90	15	15	20	20
433.91	15	20	15	15
433.92	15	20	20	20
433.93	15	10	15	10
433.94	15	15	15	15

The analysis of variance between carrier accuracy and minimum FSK deviation is tabulated in Table 10-12 and Table 10-13.

Table 10-12: Carrier Accuracy vs Minimum FSK Deviation Sum and Average Table

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	85	21.25	6.25
Row 2	4	60	15	0
Row 3	4	70	17.5	8.3333
Row 4	4	65	16.25	6.25
Row 5	4	75	18.75	6.25
Row 6	4	50	12.5	8.3333
Row 7	4	60	15	0

Table 10-13: Carrier Accuracy vs Minimum FSK Deviation ANOVA SUMMARY

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	196.4286	6	32.7381	6.470588	0.00056	2.572712
Within Groups	106.25	21	5.059524			
Total	302.6786	27				

From the table it can be seen that the practical calculated F-value is significantly greater that the theoretical F-value.

F – Practical = 6.47 >> F – Theoretical = 2.57

Because the carrier accuracy affects both the minimum and maximum FSK deviation, it can be concluded that change in carrier accuracy will vary the working range of the FSK deviation factor and so the two factors are dependent on each other.

10.4.2 Analysis of Variance – Carrier Accuracy vs. Data Pulse Width

This experiment will record the changes in the data pulse width as the carrier accuracy is varied. The first step is to calculate the boundary values of the carrier accuracy factor that will be varied in the ANOVA test. All the realizable factors including the carrier accuracy factor are programmed at their nominal value, and the command is transmitted to the tag. The tag should respond to this command to proceed further with the test. The value of the carrier accuracy factor is varied to cover the entire range that is specified in the ISO 18000-7 standard. The value of the factor is further increased and decreased beyond the standard specified values until the tag responds to the transmitted command with all remaining factors at their nominal values. This range of values for which the tag successfully responds represents the boundary values of the carrier accuracy factor for determining what factors interact with this factor using ANOVA. For different values between the boundary values previously determined, the maximum data pulse width that the tag will accept is recorded. Similarly, for the different values between the boundary values previously determined, the minimum data pulse width that the tag will accept is recorded. To calculate the maximum or minimum data pulse width the tag can accept at particular carrier accuracy, the command is transmitted at that particular carrier and data pulse width starting from the nominal value is increased/decreased from the nominal value to record the maximum/minimum data pulse width. The analysis of variance is performed on the recorded data, i.e., carrier accuracy vs. maximum data pulse width and carrier accuracy vs. minimum data pulse width. From the analysis, if carrier accuracy is independent of both maximum and minimum data pulse width then the two factors (carrier accuracy and data pulse width) are independent. If otherwise, they are dependent.

To calculate the boundary values of carrier accuracy, all factors are programmed at the standard specified nominal values and the carrier accuracy factor is varied. The value for which the tag responds and does not respond is shown in Table 10-14.

Table 10-14: Carrier Accuracy Boundary Values

Carrier Accuracy (MHz)	Tag Responded
433.87	No
433.88	Yes
433.89	Yes
433.90	Yes
433.91	Yes
433.92	Yes
433.93	Yes
433.94	Yes
433.95	No

From the table the boundary values for the carrier accuracy is selected as 433.88 MHz to 433.94 MHz. This range includes the limits as specified by the standard.

The next step is to record the maximum data pulse width accepted by the tag at each of these carrier values. Table 10-15 shows the data pulse width accepted and rejected by the tag at one carrier value - 433.92 MHz, as an example.

Table 10-15: Data Pulse Width accepted by Tag at 433.92MHz Carrier

Maximum Data Pulse Width (us)	Tag Responded
36	Yes
37	Yes
38	Yes
39	Yes
40	Yes
41	No
42	No

From the table above the maximum data pulse width accepted by tag at 433.92 MHz is 40us. This experiment is repeated four times at each value of carrier for different carrier values between the boundary values. These data are shown in Table 10-16.

Table 10-16: Carrier Accuracy vs Maximum Data Pulse Width Results

	Max. Data Width (us)			
Carrier Frequency (MHz)	1	2	3	4
433.88	40	40	40	39
433.89	39	40	40	40
433.90	40	39	40	39
433.91	40	40	39	40
433.92	39	40	39	40
433.93	40	40	40	40
433.94	39	40	39	39

The analysis of variance between carrier accuracy and maximum data pulse width is tabulated in Table 10-17 and Table 10-18.

Table 10-17: Carrier Accuracy vs Maximum Data Pulse Width Sum and Average Table

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	159	39.75	0.25
Row 2	4	159	39.75	0.25
Row 3	4	158	39.5	0.3333
Row 4	4	159	39.75	0.25
Row 5	4	158	39.5	0.3333
Row 6	4	160	40	0
Row 7	4	157	39.25	0.25

Table 10-18: Carrier Accuracy vs Maximum Data Pulse Width ANOVA SUMMARY

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.428571	6	0.238095	1	0.451174	2.572712
Within Groups	5	21	0.238095			
Total	6.428571	27				

From the table it can be seen that the practically calculated F-value is lower than the theoretical F-value.

F – Practical = 1 < F – Theoretical = 2.57

Therefore carrier accuracy factor and maximum data pulse width factor are independent.

The minimum data pulse width accepted by the tag at different carrier values is shown in Table 10-19.

Table 10-19: Carrier Accuracy vs Minimum data pulse width Results

	Min. Data Width			
Carrier Frequency (MHz)	1	2	3	4
433.88	31	30	31	30
433.89	30	31	30	30
433.9	31	30	30	31
433.91	30	30	31	31
433.92	30	31	30	30
433.93	31	30	30	30
433.94	30	30	30	31

The analysis of variance between carrier accuracy and minimum data pulse width is tabulated in Table 10-20 and Table 10-21.

Table 10-20: Carrier Accuracy vs Minimum Data Pulse Width Sum and Average Table

Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	122	30.5	0.333333
Row 2	4	121	30.25	0.25
Row 3	4	122	30.5	0.333333
Row 4	4	122	30.5	0.333333
Row 5	4	121	30.25	0.25
Row 6	4	121	30.25	0.25
Row 7	4	121	30.25	0.25

Table 10-21: Carrier Accuracy vs Minimum Data Pulse Width ANOVA SUMMARY

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.428571	6	0.071429	0.25	0.95386	2.572712
Within Groups	6	21	0.285714			
Total	6.428571	27				

From the table, it can be observed that the practically calculated F-value is lower than the theoretical F-value.

F – Practical = 0.25 < F – Theoretical = 2.57

Because the carrier accuracy does not affect both the minimum and maximum data pulse width, it can be concluded that change in carrier accuracy will not vary the working range of the data pulse width factor and so the two factors are independent on each other.

For a complete and detailed list of 2-way ANOVA refer to Appendix A (Page 171). The summary of the ANOVA between all the factors in all combination is given in Table A-1 to Table A-238. It has been found that the FSK deviation and the carrier accuracy factors are dependent on each other and will need to be tested together in the interoperability test. All other factors are independent and can be tested separately in the interoperability test.

10.5 SAMPLE SIZE OF FACTORS

After separating the dependent and independent factors, the next step is to verify that the tag under test can accept the entire range of each factor. Most of these factors (FSK Deviation or Data Pulse Width) can accept values over a range of numbers. Theoretically the factor has an infinite set of values that are possible. In practicality, it is not possible to test every possible value in this infinite set to achieve a 100% confidence on the results. Therefore a procedure where only a limited number of the values from the infinite set are tested to comment upon the entire set with a confidence less than or equal to 100% is essential.

The strategy of value selection from the infinite set, found to be optimal, is based on Accept on Zero (AoZ) sampling. This method provides the number of samples for a given confidence level that are to be tested to comment upon the entire range of values for that factor.

The formula to calculate the sample size is:

$$n = \frac{\log \beta}{\log(1 - LTPD)}$$

Where, 1-β is the confidence level and LTPD is the maximum percentage defective that is acceptable.

10.6 NORMALIZED LTPD – DERIVATION OF INDIVDUAL LTPD

In designing traditional sampling plans (single, double or multiple) of a particular lot with major and minor characteristics, it is acceptable to design a sampling plan with lower AQL to test the major characteristics (which produces a tighter test) and design a sampling plan with an higher AQL to test the minor characteristics (which makes the test comparatively lenient) [13].

The normalized LTPD (NLTPD) value is the LTPD value of interoperability test entered as an input into the software developed. The LTPD value to incorporate individual factor experiment data obtained through previous compliance tests is obtained as a function of the normalized LTPD (NLTPD).

The equation to find individual LTPD is:

$$LTPD = (NLTPD)^{\left\{(1-J)^{Y}\right\}}$$

The equation above maps the normalized LTPD value to corresponding LTPD values for individual factors. When the normalized LTPD value is 0 (no error in base factor; ideal case), all individual LTPD values are mapped to 0. When the normalized LTPD value is 1 (worst case; everything is incorrect), all individual LTPD values are mapped to 1. Within the boundary values, the normalized LTPD must be mapped to a higher value if the factor is more prone to errors (which will increase the number of samples to be tested within the range of values defined by the standard). The normalized AQL value must be mapped to a lower value if the factor is less prone to errors (which will decrease the number of samples to be tested within the range of values defined by the standard). The equation to calculate individual LTPD from a normalized LTPD is derived to satisfy the boundary conditions and the intermediate conditions. The solution to the conditions mentioned above is not unique. This is not the only function that will satisfy the conditions but one of the solutions that satisfies the specified conditions.

The curves of Figure 10-3 are obtained by solving the equation to find individual AQL for different values of NLTPD, J and Y.

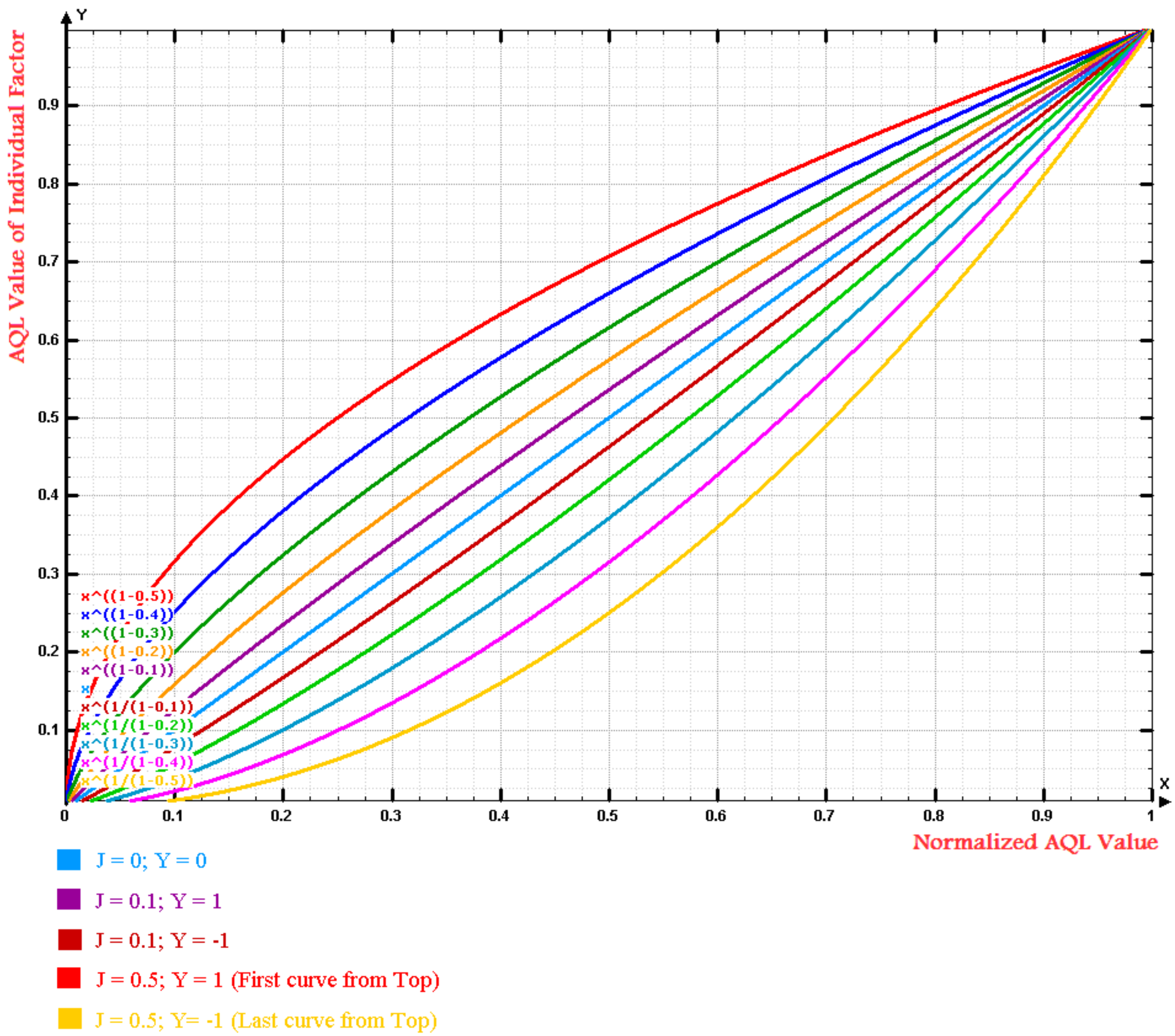

Figure 10-3: Weight Curves

The individual AQL value of the factor is calculated from the Weight Curves shown in Figure 10-3 which maps the normalized LTPD value to individual LTPD values depending on J and Y. The individual LTPD value of the factor is function of the normalized LTPD (NLTPD), factor J and factor Y. The value of variable J is selected to adjust the (individual) LTPD of current factor when compared with the base factor. Variable Y has a value of ±1. The value of Y is -1 if there is an increase in error percentage. The value of Y is +1 if there is a decrease in the error percentage. The decision of whether there is an increase or decrease in error percentage from the base factor and its value is decided upon analyzing the results of conformance tests.

The value of the 'J' for each factor will depend upon the results of the conformance tests, the knowledge of the hardware limitations in the GOLD Active Reader, and the experience gained from building the GOLD Active Tag which provided the opportunity to research the hardware components available in market and understand the effort required to realize every factor in building an active tag.

The J and Y values used in the development of the interoperability test are tabulated in Table 10-22. In this implementation, the most error prone factor and important factor, which is the data pulse width factor, is considered as the base factor (J = 0 & Y = 1). The LTPD of all other factors is adjusted so that it is greater than the NLTPD.

Table 10-22: J and Y values of all factors

Factor	J Value	Y Value
FSK Deviation	0.1	1
Carrier	0.7	1
Wakeup Length	0.5	1
Co-Header Length	0.5	1
Wakeup Pulse Width	0.3	1
Co-Header Pulse Width	0.3	1
Preamble Pulse Width	0.3	1
Sync Pulse Width	0.3	1
Data Pulse Width	0	1
End Pulse Width	0.4	1
Time bet. Wakeup & Co-Header	0.3	1
Time bet. Wakeup & Command	0.3	1

Because the number of failed cases of the FSK deviation factor closely follows the data pulse width factor, its J value is assigned 1. All pulse widths are assigned a J value of 0.3, justifiable by the percentage of failed cases from conformance test results. The end pulse factor, though having a high fail percentage is given a J value of 0.4 because it does not affect the interoperability property of the tag (most tags can identify the command even if the end pulse is completely missing). The wakeup pulse length and the co-header length seldom fail (mainly due to high degree of variability allowed in the standard) but the J value is 0.5 less than that of carrier J value 0.7 which also seldom fails because there is minor degree of ambiguity in realizing the wakeup co-header sequence (Is co-header a part of wakeup or should it follow the wakeup?). The remaining two factors, the time between wakeup and co-header and time between wakeup sequence and command, are assigned a J value of 0.3. These factors are not implicitly defined in the standard and by current definition never fail in the conformance test.

The maximum possible values of each factor limited by hardware in the current setup are tabulated in Table 10-23. Factors not mentioned in the table are factors that do not require acceptance sampling for testing.

Table 10-23: Maximum Possible Values of each factor limited by hardware

Factor Name	Possible Values
FSK deviation	20
Carrier	27
Preamble width	120
Sync pulse width	200
Data pulse width	72
End pulse length	144
Wake up pulse width	4
Wake up length	76562
Co-header pulse width	10
Co-header length	40
Time between wake up and co-header	12000000
Time between end of wake up sequence to start of command preamble	29000

As an example to understand the normalization procedure better, consider three different factors – FSK Deviation, Data Pulse Width and Wakeup Pulse Width. Assume that the normalized LTPD value (NLTPD) = 0.05 and β = 0.05. As Data Pulse Width factor is the base factor, LTPD(DPW) = 0.05 and J(DPW) = 1.

From Table 10-22, J(FSK) = 0.1, Y(FSK) = 1, J(WPW) = 0.3 and Y(WPW) = 1. Using the mapping function LTPD(FSK) = 0.067 and LTPD(WPW) = 0.122.

From the binomial distribution function, the number of samples to test is N(DPW) = 58, N(FSK) = 43 and N(WPW) = 23.

But from Table 10-23, the maximum possible samples of wakeup pulse width is limited to 4 due to hardware limitations. Therefore the LTPD of WPW is adjusted so that N(WPW) = 4.

$$Adjusted\ \ LTPD = 1 - \beta^{1/n}$$

After adjustment LTPD(WPW) = 0.53. This value is passed through the inverse mapping function to obtain the final LTPD of wakeup pulse width that is used when displaying the results.

$$Final\ \ LTPD = (Adjusted\ \ LTPD)^{\frac{1}{1-j}}$$

The Final LTPD of wakeup pulse width factor is equal to 0.40.

10.7 INTERPRETATION OF RESULTS

After testing all the factors of the RFID system under test, consider the following two cases [18].

Case 1: The RFID system operates with each factor, at each sample tested

In this case the result is "The RFID Active Tag under test is Interoperable". The results of each factor are presented in the format below.

"The factor is Interoperable. With a confidence level of (1-β)%, the error in the interoperability property of the factor is less than LTPD%."

Case 2: The RFID system rejects at least one factor, at minimum one value

In this case the result is "The RFID Active Tag under test is not Interoperable". The presentation of results of factors that pass the test are discussed in case 1. The results of factors that fail the test as presented in the format below along with the values at which the factor failed.

"The factor is not Interoperable. With a confidence level of (1-β)%, the error in the interoperability property of the factor is greater than LTPD%."

In section 10.6 the LTPD values of Data Pulse Width, FSK Deviation and Wakeup Pulse Width factors has been calculated.

Assuming that the tag under test replied to all variations in all three factors the result of the test is shown below.

"Data Pulse Width factor is Interoperable. With a confidence level of 95%, the error in the interoperability property of the factor is less than 5%."

"FSK Deviation factor is Interoperable. With a confidence level of 95%, the error in the interoperability property of the factor is less than 5%."

"Data Pulse Width factor is Interoperable. With a confidence level of 95%, the error in the interoperability property of the factor is less than 40%."

The interoperability test can be repeated with different zero sampling plans (different set of normalized LTPD, β values) and ranges of factors. If the ISO committee decides to allow certain percentage defective in each factor, the zero sampling procedure can be replaced with sequential sampling in the entire methodology.

10.8 COMPARISON OF DIFFERENT TESTS

The test procedure and analysis described are independent of the hardware and software modules that can be used to realize it. In such a situation it should be possible to compare tests performed on the same hardware or on different hardware. The comparison is valid only if the same mapping functions are used to normalize the LTPD (or no normalization scheme is used as agreed by both parties) and one of the parameters is held constant in the sampling plan (either β is constant or LTPD is constant). It is common practice to hold β constant (Refer to Strength of Statement in section 13.2). In such a scenario, the LTPD of each factor is compared.

Due to the number of factors considered for the interoperability test, though the confidence of an individual factor is high in the nineties, combining all the confidence levels of all the factors by multiplication would result in a significantly small and insignificant confidence level for the time of test. Therefore the results of each factor are presented separately as discussed in previous section. Hence each factor needs to be compared separately. The test setup with lower LTPD while β is held constant or the test setup with higher (1- β) while LTPD is held constant, by definition will be a more stringent test in comparison.

The next step in comparison is possible if there is an agreement to migrate to grey box testing as to current black box testing. In grey box testing, the overall design data about the tag is revealed by the vendor. The specifics of the design are not disclosed.

It needs to be understood that although there are factor considered for the interoperability test that accept values over a range on the real number line, because the tag under test is a digital electronic circuit, there is a certain level of digitization that limits the smallest change that can be recognized by the tag. For example, if a clock frequency to sample the data from the FM demodulator is 10MHz, then the smallest change in pulse widths that can be recognized by the tag is 100ns. Even if the GOLD reader can very its pulse widths by 10ns, it cannot be perceived by the tag under test. This converts the set of values of each factor from an infinitely large set to a finite set of numbers. Therefore the total values to test, the addition of the number of items in the set of values of each factor, will be a finite number as opposed to the current number which is infinite. In such a scenario, it is possible to calculate a measure of test (MoT) using the formula:

$$MoT = \frac{Total\ Values\ Tested}{Total\ Values\ to\ Test}$$

To compare different test setups using MoT concept, the test that can generate a smaller MoT value is by definition more complete. The ideal value of MoT is 1 assuming the best resolution used in the test does not exceed the resolution of the tag under test.

11.0 IMLEMENTATION OF THE METHODOLOGY

The methodology of the interoperability test has been described in detain in section 10.0 . This chapter introduces the practical implementation of the methodology and also describes in detail the test setup that has been implemented using commercial equipment.

To realize the methodology, the first step is to program a commercially available radio frequency signal generator (RFSG) to emulate an active RFID reader (and/or active RFID tag) with the ability to vary the different parameters affecting interoperability while transmission of commands (responses in the case of tag) conforming to ISO 18000-7 standard.

Figure 11-1 displays the general block diagram to realize the interoperability test both for the active tag and active reader. The document explains the block diagram considering testing the active tag as an example. The same methodology applies to the interoperability testing of the active reader.

The test setup will include a commercial RF signal generator that can be programmed by the user to generate custom commands conforming to the ISO 18000-7 standard within the timing specifications described in the standard. The tag under test either correctly decodes the commands and replies with the appropriate response or fails to respond to the custom commands. Since the testing is intended to be a black box test, the internal states and signals of the tag under test are not probed. The analysis is completely based on the RF response transmitted or not transmitted by the tag.

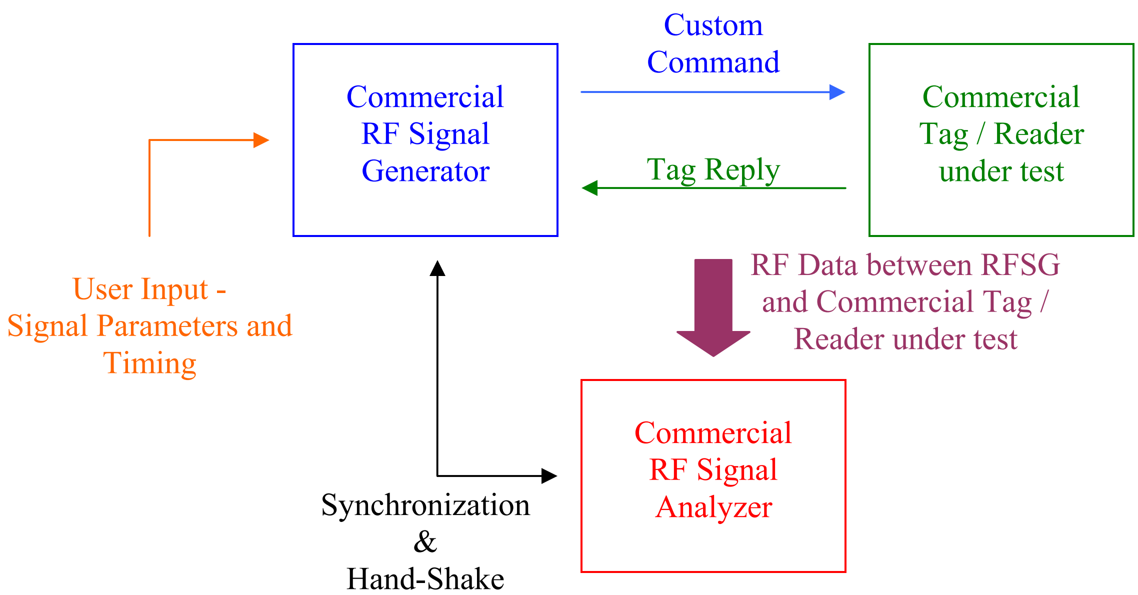

Figure 11-1: Interoperability Test Methodology – General Realization Block Diagram

The RF data transfer between the RFSG and the tag under test is captured using an RF signal analyzer (RFSA) or a real time spectrum analyzer (RTSA) to determine if there is a response from the tag and to analyze the response to verify it is intended. There is a synchronization and hand-shake logic designed between the RFSG and the RFSA either in software or in hardware as supported by either device. This logic determines the time and characteristics of command transmission by the RFSG and the time and analysis requirements of RF data capture by the RFSA.

The entire setup can be automated by introducing a PC or a workstation into the test setup that can execute a sequence of steps, altering the command parameters, analyzing data from RFSA and synchronizing the entire hardware throughout the test. Automation is highly recommended because the time required for such an experiment is definitely unattractive and unsuitable for manual operation.

The test setup can be interfaced by the user through a simple graphical user interface (GUI) that can be used to set the limits of individual factors, the confidence level requirements of the experiment and initiate the experiment.

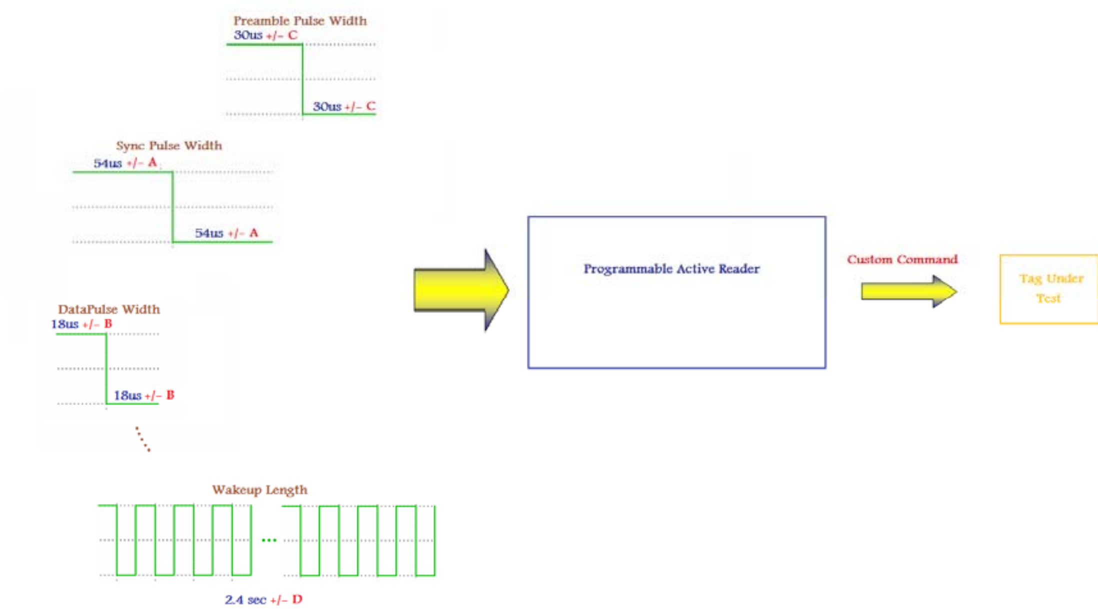

Figure 11-2: GUI Functionality

Figure 11-2 shows the functionality of the GUI to control the interoperability test setup. The limits of all the factors affecting interoperability are specified. The GUI will vary the values of factors between the limits and instruct the RFSG to transmit custom commands to the device under test.

The setup for testing the interoperability of an active RFID reader is similar. The commercial RFSG is programmed to emulate a tag where the different test parameters are programmable by the reader. Realizing the programmable tag is more challenging than realizing the programmable reader due to timing constraints imposed on the design of the tag. In active RFID under ISO 18000-7, the reader always initiates communication. This makes it relatively simple to realize the synchronization and data analysis modules in designing the test setup to test the tag. In designing the setup to test an active reader, this challenge can be achieved by introducing an FPGA (replacing or aiding the PC) into the setup that can interface between the RFSG and the RFSA, analyzing the RF data in real time and transmitting the required response to the reader under test without violating the timing constraints set forth by the standard. A bigger challenge is automating the test setup as the current standard(s) that guide(s) the development of a commercial active RFID reader do not standardize the interface to the reader. Different readers utilize different interfaces like USB, Ethernet and RS232 to communicate with the user through a PC. This lack of a standard interface poses a huge setback when automating the reader interoperability test. Even if there is a standard interface, the commands required to communicate with the reader through the same interface may differ due to the numerous hardware solutions (micro processors and micro controllers etc.) available in realizing commercial equipment. Thus automating the test setup would require additional details about the internal design of the reader and its data encoding and decoding. If it was possible to realize the reader interoperability test overcoming all the limitations explained, the methodology of the interoperability test is still the same and valid.

11.1 TAG INTEROPERABILITY TEST SETUP – BLOCK DIAGRAM

Having understood the different modules that are essential in realizing the interoperability test setup to test an active RFID reader and tag, the setup that is designed to test interoperability of an active RFID tag to demonstrate the practicality of the methodology is explained in this section. The hardware and software modules used in the setup can be replaced with other commercially available equipment.

The RFSG ni5671 from national instruments is programmed to emulate an active RFID reader with the ability to program the signal parameters and vary the timing specifications within the ISO 18000-7 standard. The best resolution of the different factors affecting interoperability that was achieved using this particular RFSG is recorded in Table 10-4. The ni5671 RFSG is programmed to vary each of the independent factors for the required unique values within the limits defined by the standard to best satisfy the confidence levels of the experiment one after the other. Upon completion of all the independent factors, the set of dependent factors is varied for all possible combinations.

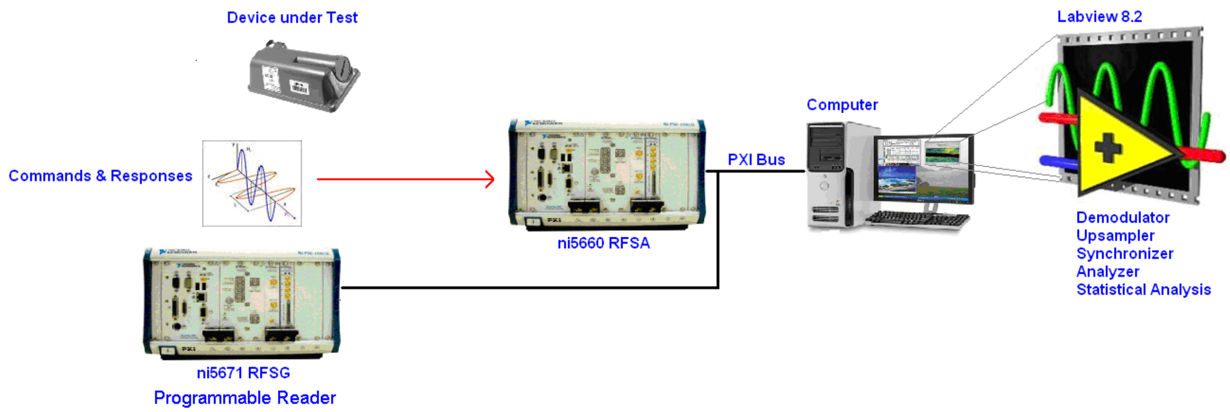

Figure 11-3: Test Setup for Tag Interoperability Experiment

The RF data transfer between the programmable reader and the tag under test is captured by the ni5660 RFSA also from National Instruments. The ni5671 RFSG and ni5660 RFSA can only be programmed through LabView software also developed by National Instruments. The synchronization between the RFSA and RFSG is programmed in software using LabView 8.2. the RF data captured by ni5660 is transferred as raw IQ data to the PC where FM demodulation is performed in software. The demodulated waveform is then analyzed for the tag response and the same is decoded to verify that the response from the tag is appropriate and intended. The RFSA and the RFSG are connected via the PXI 8331 bus that can support up to a peak 132Mbytes per second and an average of 72Mbytes per second data transfer rates between the PC and the RFSG/SA internal memory.

If the RFSA and the RFSG are in the same NI chassis, the maximum supported internal memory of 256Mbytes is shared between them to store the building blocks required for command transmission and to capture RF data. In such a case, the parameters in the collection command transmitted by the RFSG should be adjusted so that the tag will definitely reply within the maximum data capture length possible by the RFSA. The building blocks need to be selected so that the command transmission is possible with the best resolution and minimum memory requirement.

11.2 GENERATION OF COMMANDS

This section explains the different design steps and options in selecting the building blocks to generate commands using ni5671 RFSG. Using the concepts of operation, programming and principle of IQ modulation as described in detain in section 9.0 , two possible techniques are developed to realize the necessary signals required to be transmitted by the programmable reader within the limitations of the available memory and phase continuity requirements. Knowledge about the realization of these signals is very useful when realizing the same on other commercial RFSGs as most commercial RFSGs use the same fundamental concept of IQ modulation to generate required modulated signals and are limited by the memory available. The two techniques described here have a tradeoff between the sampling frequency (maximum possible resolution) and the memory requirement. Both techniques are used to realize different portions of the protocol signals together forming the entire collection sequence in active RFID while obtaining the maximum possible resolution in each factor.

11.2.1 Method 1 – Modulate and Join

In this method, as the name suggests, the different pieces in the waveform are modulated first and then joined.

In this method, the first step is to determine the number of fundamental frequency components and their frequencies (time periods) in the signals that are to be transmitted. The next step is to modulate each of the building blocks and store them in the internal memory of the RFSG at different memory locations associated with different names. To generate the entire command, the script mode of the signal generator can be used to transmit the modulated building blocks one after the other generating the entire waveform.

The advantage of this method is that when transmitting signals of duration in seconds, with only one or two fundamental frequencies, only a small portion of the signals can be loaded into memory and transmission can be repeated to generate the entire waveform saving on memory. The disadvantage of this method is that the sampling rate must be chosen with great care so that the same intermediate frequency can generate waveform without phase discontinuity. The principle of this method is shown in Figure 11-4. The figure shows the final waveform with phase discontinuity.

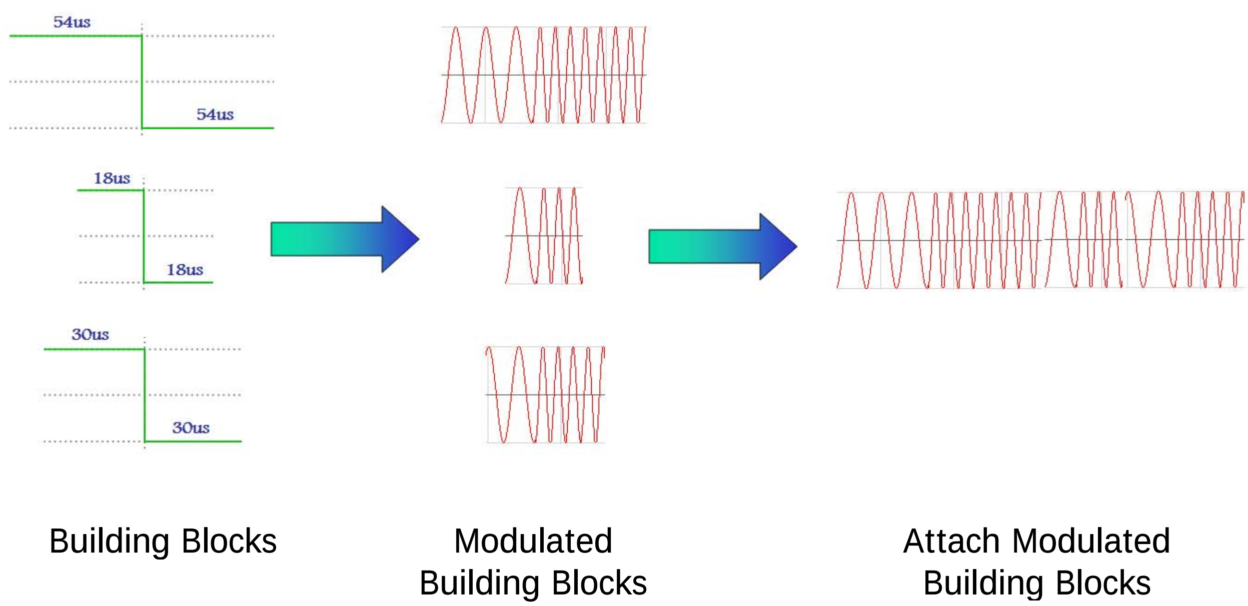

Figure 11-4: Modulate & Join Method to generate signals

Consider the generation of the wakeup signal for 2.4 seconds followed by the generation of the co-header signal for 100ms. In this case it is not possible to load the entire wakeup into the RFSG memory. Therefore one time-period of wakeup (16us low + 16us high) is modulated and stored in memory. Similarly one time-period of co-header (50us low + 50us high) is modulated and stored in memory. The wakeup is generated for 2.4 seconds followed by the co-header without any delay between them by repeating the building blocks for 75,000 times and 1000 times respectively. Because the two frequencies are not equal or multiples of one another, the sampling rate that will satisfy both the frequencies has to be determined through trial and error. It is possible that there will not be any sampling frequency that can configure the RFSG to generate both the frequencies one after the other with zero delay in between them. If more than one sampling frequency will satisfy the requirement, the highest sampling frequency is preferred as it increases the resolution of the factors.

11.2.2 Method 2 – Join and Modulate

In this method, as the name suggests, the different pieces in the waveform are joined first and then the entire signal is modulated and loaded into the memory of the RFSG.

In this method, the first step is to determine the number of fundamental frequency components and their frequencies (time periods) in the signals that are to be transmitted. The next step is to join each of the building blocks in the required order. The final step is to modulate the entire signal and store it in the internal memory of the RFSG. The entire signal is transmitted when required.

The advantage of this method is that when transmitting signals of significantly small duration, with multiple (3 or more) fundamental frequencies, the entire signal can be modulated at once at very high sampling frequencies achieving very precise resolution for factors without phase discontinuity as the memory requirement is low. The disadvantage of this method is that it is applicable only to short signals of duration in milli-seconds. The principle of this method is shown in Figure 11-5. The figure shows the final waveform without phase discontinuity.

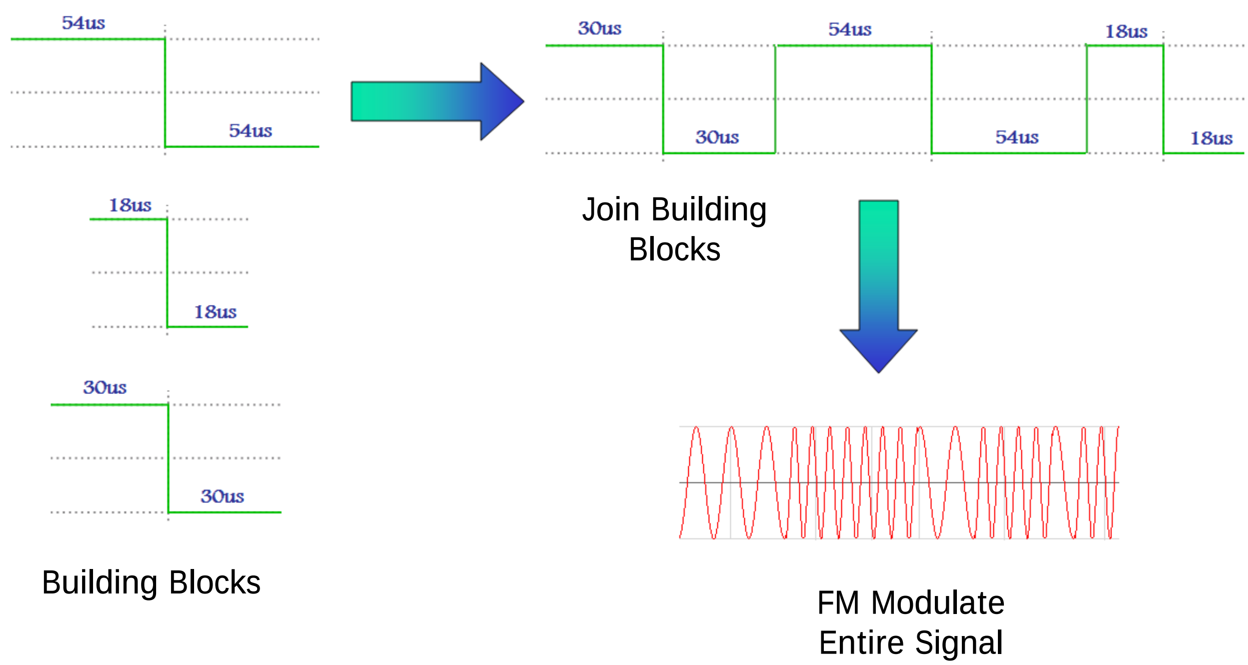

Figure 11-5: Join & Modulate method to generate signals

Consider the transmission of the commands with different fundamental frequencies (preamble, sync pulse, data, initialization pulse, termination pulse and end pulse). It is impossible to find a single sampling rate to generate all the different fundamental frequencies. Therefore it is preferable to modulate the entire command at once. because the length of the command is in the order of milli-seconds, the resolution of all the parameters in the command can be as low as 10ns.

12.0 INTEROPERABILITY TEST SUITE

This chapter explains in detail the objective, algorithm and procedure to use the interoperability test suite developed to setup the hardware, perform the experiment and record the interoperability status of an active RFID tag.

Test Objective

The objective of this test to verify that the tag under test accepts commands with variations in all factors considered within the ISO 18000-7 standard to comment on its interoperability property with a level of confidence.

Factor Limiting Inputs

The limits of each factor within which the interoperability test is performed are presented to the user on the front panel with the standard defined limits as the default values.

1. Maximum FSK Deviation
2. Minimum FSK Deviation
3. Maximum Carrier Frequency
4. Minimum Carrier Frequency
5. Minimum Number of preamble pulses
6. Maximum Preamble Width
7. Minimum Preamble Width
8. Maximum Sync Pulse Width
9. Minimum Sync Pulse Width

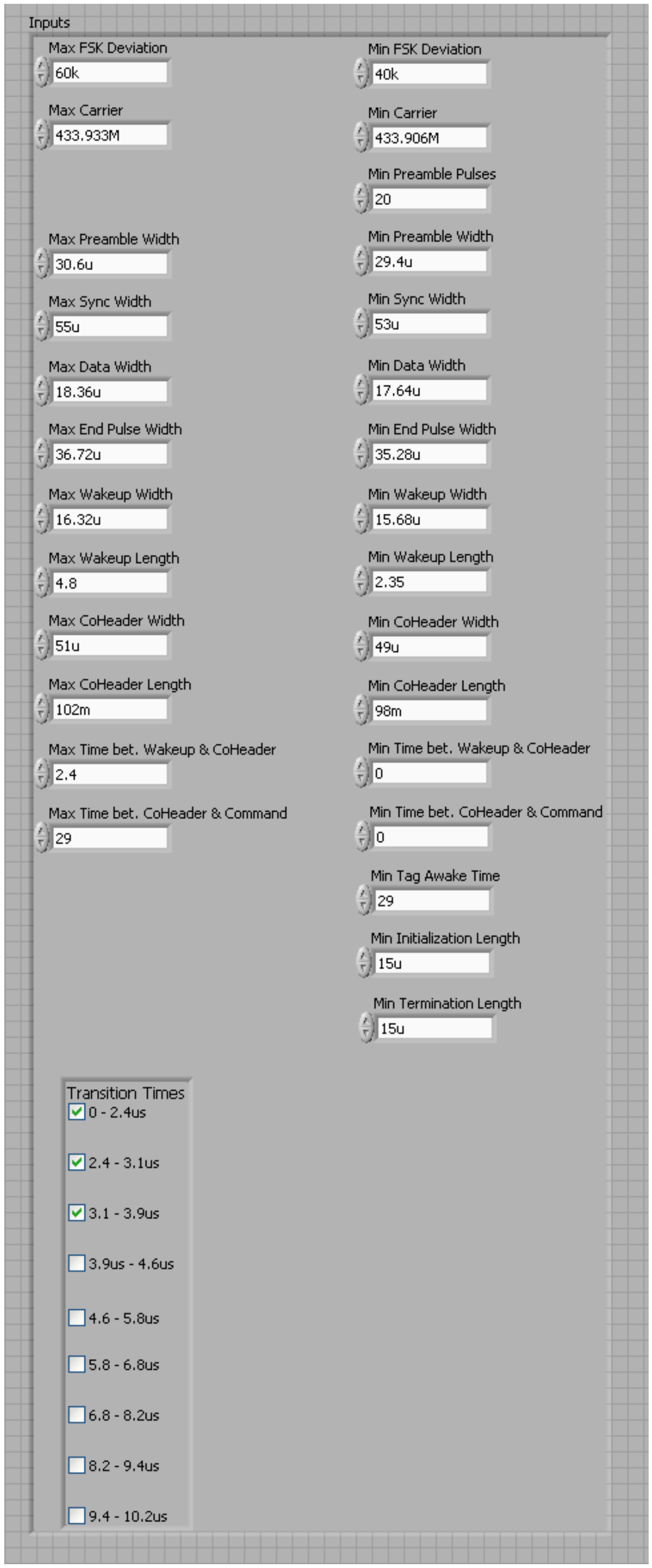

Figure 12-1: Factor Limits - Inputs

10. Maximum Data Pulse Width
11. Minimum Data Pulse Width
12. Maximum End Pulse Width
13. Minimum End Pulse Width
14. Maximum Wakeup Pulse Width
15. Minimum Wakeup Pulse Width
16. Maximum Wakeup Length
17. Minimum Wakeup Length
18. Maximum Co-Header Pulse Width
19. Minimum Co-Header Pulse Width
20. Maximum C0-Header Length
21. Minimum Co-Header Length
22. Maximum Time between Wakeup & Co-Header
23. Minimum Time between Wakeup & Co-Header
24. Maximum Time between Wakeup Sequence & Command
25. Minimum Time between Wakeup Sequence & Command
26. Minimum Tag Awake Time
27. Minimum Initialization Length
28. Minimum Termination Length
29. Transition Time Discrete Groups (All transition times of command will be in group)

Interoperability Test Parameters

The remaining inputs to associate the interoperability test with a specified confidence level and to record the test results are selected by the user.

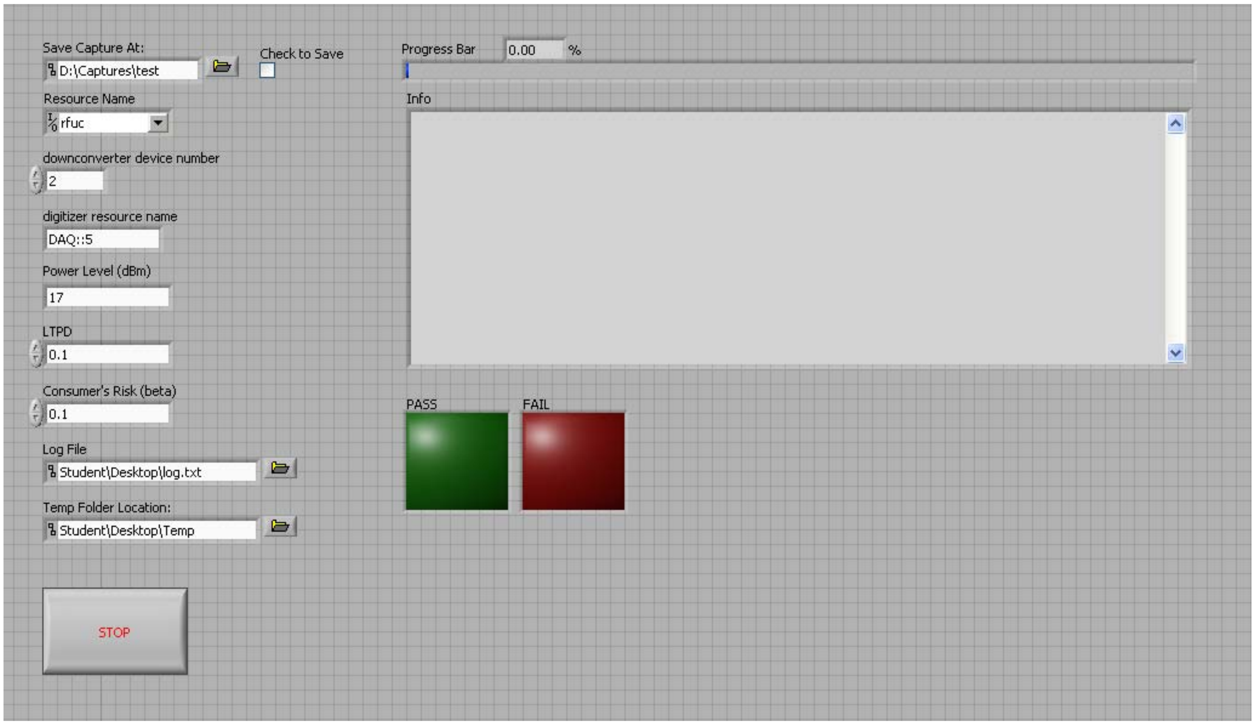

Figure 12-2: Front Panel of Interoperability test Software

1. LTPD
2. Consumer's Risk (Beta)
3. Log File – To record all the observations of the Test
4. Temporary Folder Location – a local folder on the hard disk that will be used by the software.
5. Power Level (dBm) – Power of transmission by ni5671.
6. Check to Save – Check this box to save all commands and tag responses. This option will require a minimum of 50GB of hard disk space.
7. Save Capture At – All the commands and tag responses will be saved in this folder.
8. Resource Name – Open Measurement and automation Explorer. Look in: My System >> Devices and Interfaces >> NI-DAQmx Devices
9. Down Converter Device Number – Open Measurement and automation Explorer. Look in: My System >> Devices and Interfaces >> NI-DAQmx Devices

10. Digitizer Resource Name – Open Measurement and automation Explorer. Look in: My System >> Devices and Interfaces >> Traditional NI-DAQ (Legacy) Devices

Outputs

The results of the interoperability test are displayed on the front panel.

1. Progress Bar – Displays the current progress of the Test
2. Info – Displays a record of the test performed and updates after every command transmission.
3. Pass or Fail Indicators – Provide a quick binary reference of the overall Interoperability Test result.

Procedure to use the Interoperability Test Suite

1. User will input all the required parameters for testing mentioned above.
2. User will execute VI by pressing the  button in VI window.
3. The interoperability test is performed. If the selected AoZ sampling plan is not achievable due to hardware limitations, the best possible AoZ sampling plan is implemented.
4. The “Info” data is updated after transmission of every command.
5. The final test results of all factors are displayed individually in the “Info” area.
6. The Pass or Fail indicators display the overall test result.
7. If the option to save every command and response RF data is selected, the saved waveforms can be loaded into the “Load and See” VI to verify or analyze the results.

Algorithm of the Test

1. Calculate Individual LTPD from Normalized LTPD entered by user.
2. Calculate the sample size for each factor depending on LTPD and Beta.

3. Adjust LTPD keeping Beta constant if the sample size is beyond realization due to hardware limitation.
4. For all Independent Factors affecting Interoperability, vary the value of each factor between limits entered by the user and record the tag reply.
5. For all Dependent Factor Sets affecting Interoperability, vary the values of factors in that set to achieve all possible combination of factor values between limits entered by user and record the tag reply.
6. Verify that the tag replied to all commands transmitted.

13.0 RESULTS

The results of the research are discussed in this section. A few waveforms where some of the factors are varied from the nominal values in the standard are shown to demonstrate the capability of the GOLD programmable aggressive active RFID reader. Detailed analysis is provided on the Region of Confidence (defined in Section 13.2) of each factor as implemented using the test setup discussed in Section 11.0 .

13.1 CUSTOM COMMANDS

Figure 13-1 displays the collection command from the GOLD programmable reader with all factors at the nominal values.

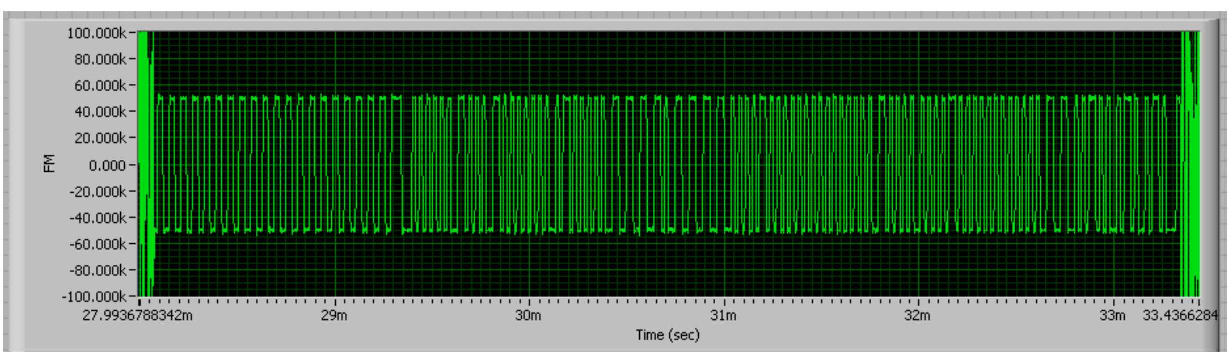

Figure 13-1: Command with all factors at nominal values

Figure 13-2 displays a portion of the collection command from the GOLD programmable reader with the transition time from symbol high and symbol low between 9.4us to 10.2us.

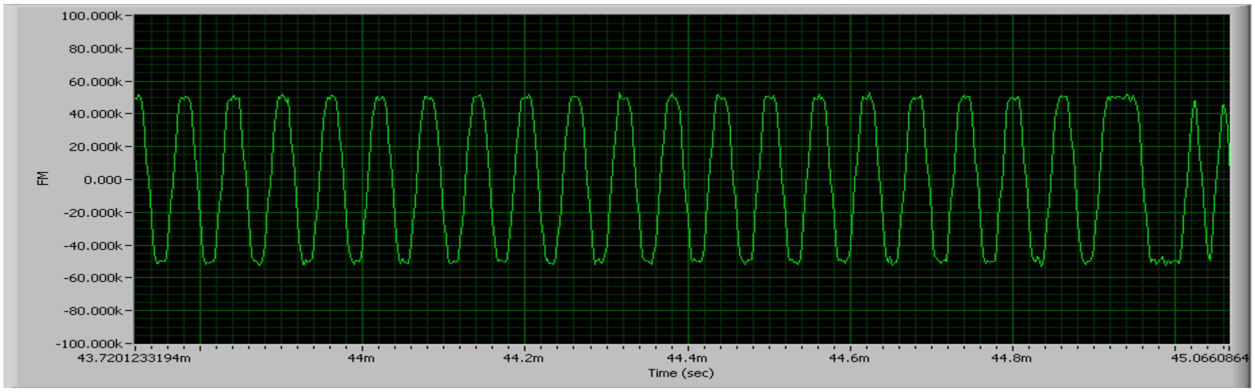

Figure 13-2: Command (Preamble Portion) with Transition Times between 9.4us to 10.2us

Figure 13-3 displays the collection command from the GOLD programmable reader with the FSK deviation of symbol high and symbol low at 40kHz instead of the nominal value.

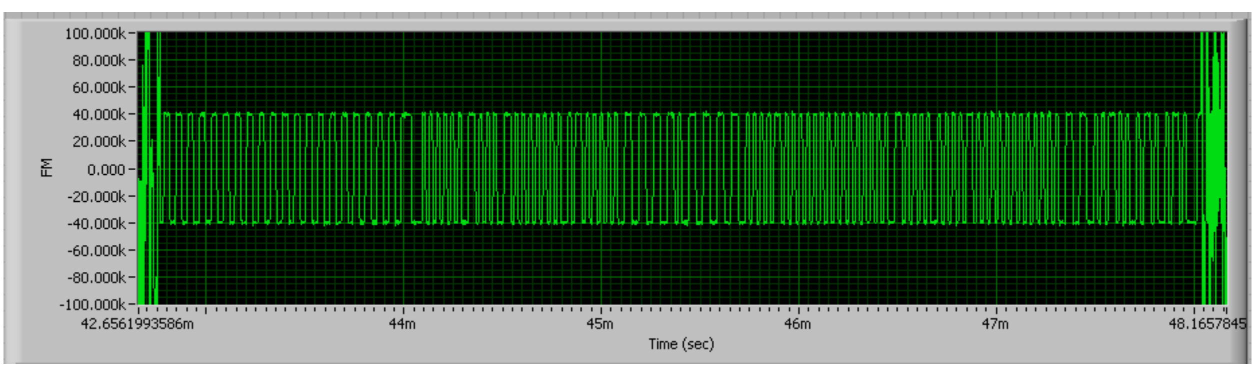

Figure 13-3: Command with FSK Deviation of 40kHz

Figure 13-4 displays the collection command from the GOLD programmable reader with the FSK deviation of symbol high and symbol low at 60kHz instead of the nominal value.

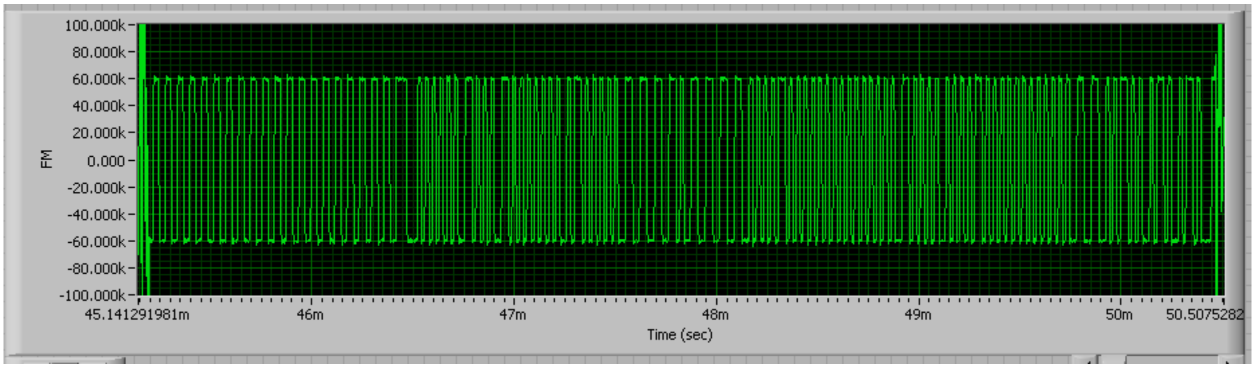

Figure 13-4: Command with FSK Deviation at 60kHz

Figure 13-5 the collection command from the GOLD programmable reader with 40 preambles instead of the minimum number of preambles.

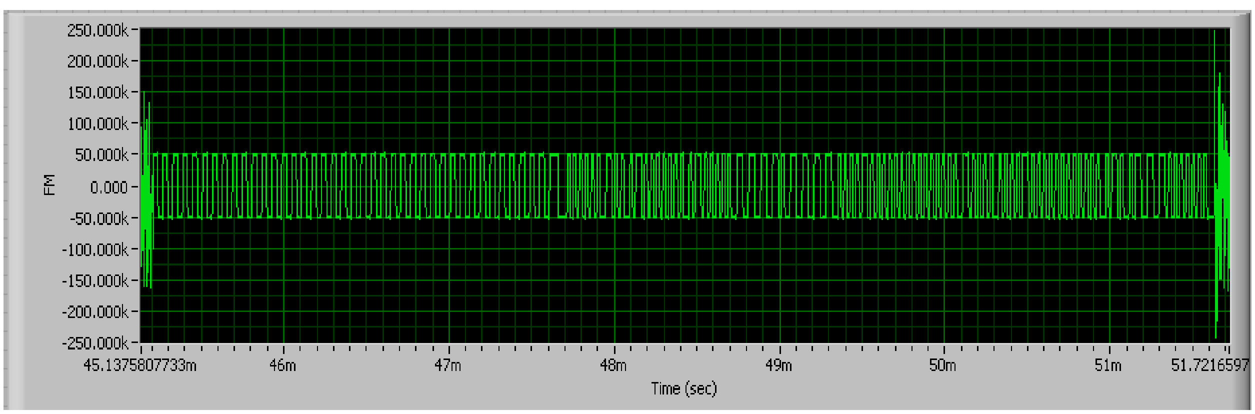

Figure 13-5: Command with 40 Preambles

Similarly, different characteristics of the command and the protocol timings of the standard can be modified by varying the settings on the GUI. The example waveforms presented here are selected to be distinct to the viewer.

13.2 REGION OF CONFIDENCE

The Region of Confidence (RoC) graph explains the relation between the confidence level, error in the interoperability property and the sample size that is possible in the test setup.

The RoC graphs are plotted as a quick reference to understand the best possible test scenario (Confidence Level and Percentage Error Values) for each factor using current hardware and test setup. In an ideal case, the RoC of a factor in the experiment is the entire area of the triangle between the x- axis, y-axis and the straight line with slope '-1' and y-intercept '1'.

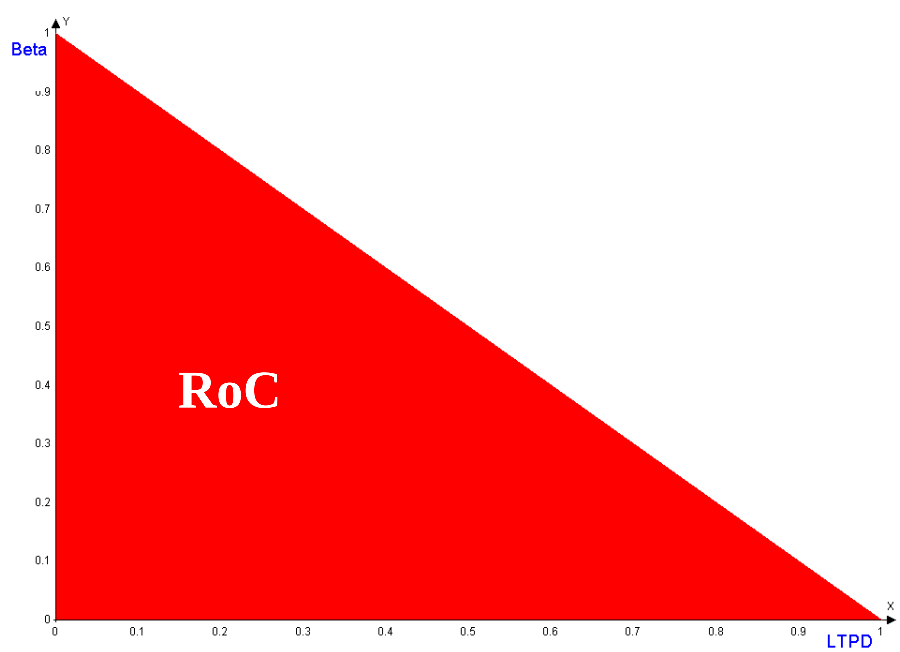

Figure 13-6: Ideal RoC

In AoZ sampling there is always a tradeoff between “Strength of the Statement” vs “Strength of the Result”. For example, when explaining the reliability of equipment, “With 10% confidence, this equipment works for 90% of the time” is giving strength to the result. Similarly, interpreting the same result as “With 90% confidence, this equipment works for at least 10% of the time” is giving strength to the statement. It has to be noted that the confidence level and error percentage are interchangeable in the ideal RoC case but not always in an RoC calculated from a practical experiment. It is the personal preference of the individual to choose between the two cases. It is recommended to strengthen the statement rather than the result is followed in this dissertation and the developed interoperability software.

The RoCs of all the different factors tested using AoZ sampling using the current test setup is plotted from Figure 13-7 to Figure 13-8 with β on the y-axis and LTPD on the x-axis. It has to be noted that the graph when n = 1 is not linear in this application as LTPD is normalized. The origin (100% confidence with zero percentage error) is not part of any RoC graph as all equipment at some level is digital and therefore can accept only discrete values.

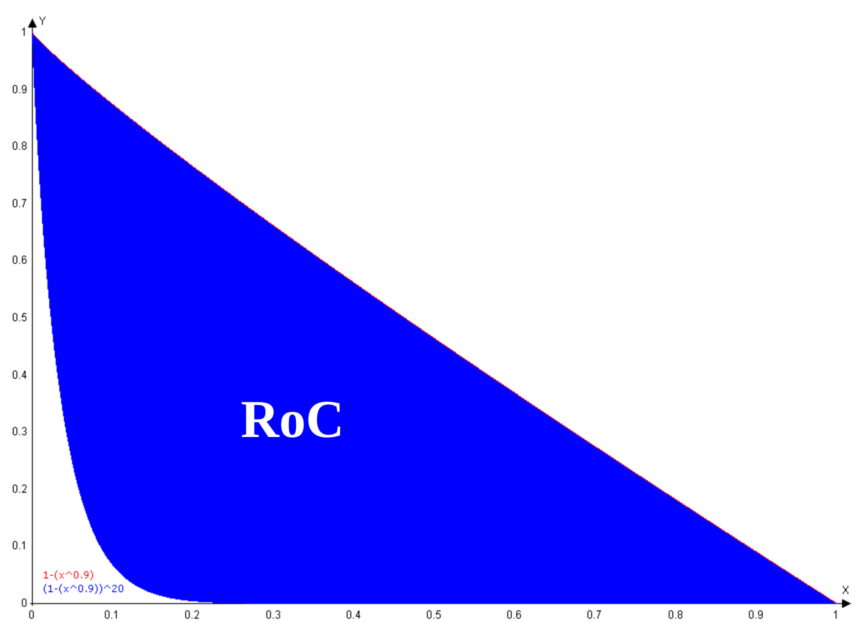

Figure 13-7: RoC of FSK Deviation Factor (n=20)

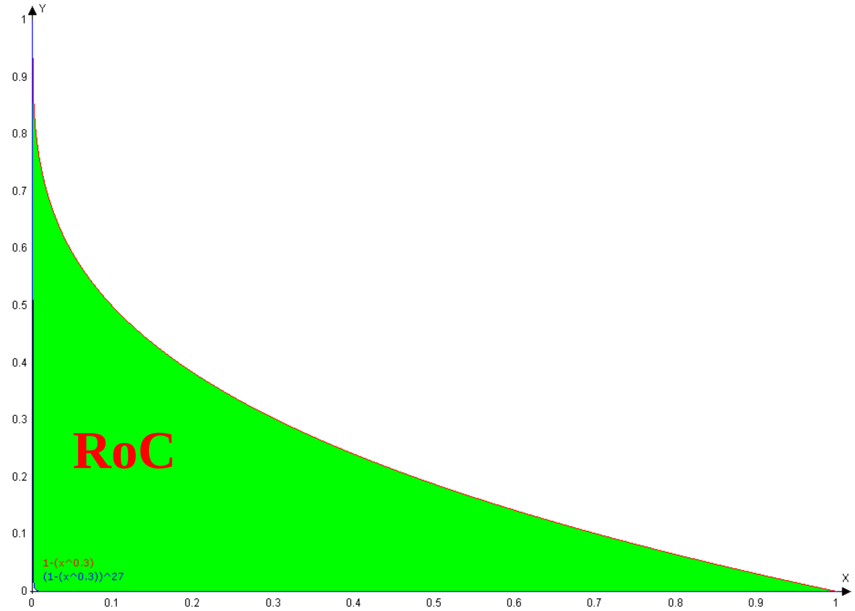

Figure 13-8: RoC of Carrier Factor (n=27)

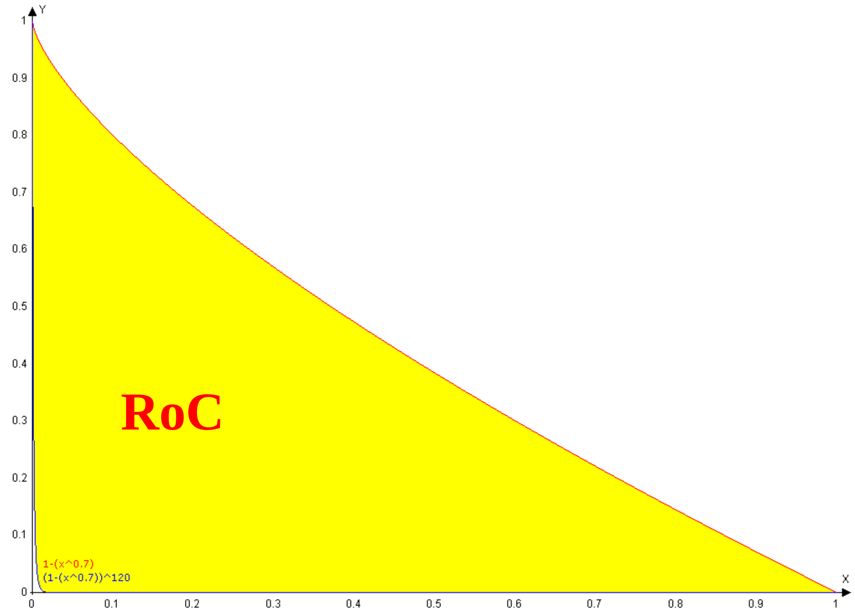

Figure 13-9: RoC of Preamble Pulse Width Factor (n=120)

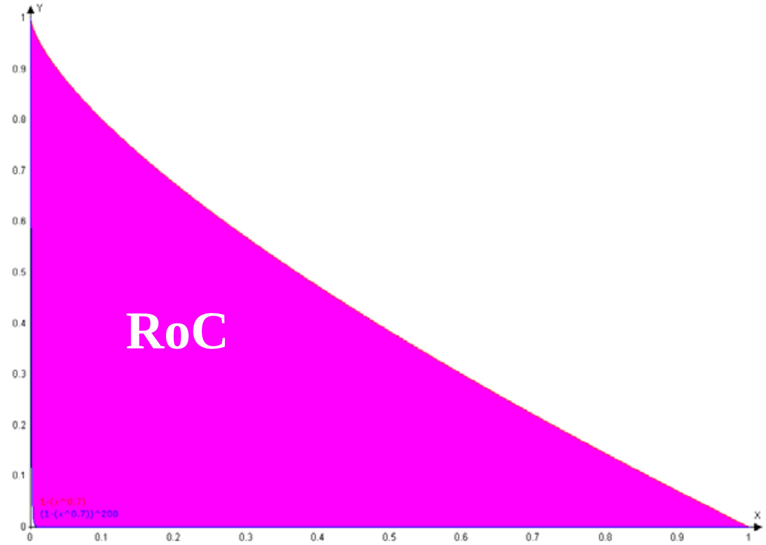

Figure 13-10: RoC of Sync Pulse Width Factor (n=200)

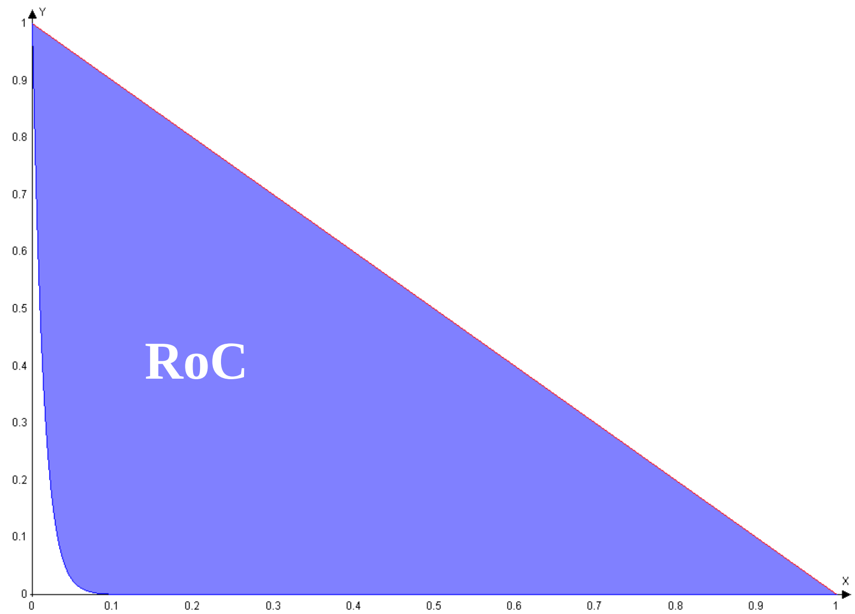

Figure 13-11: RoC of Data Pulse Width Factor (n=72)

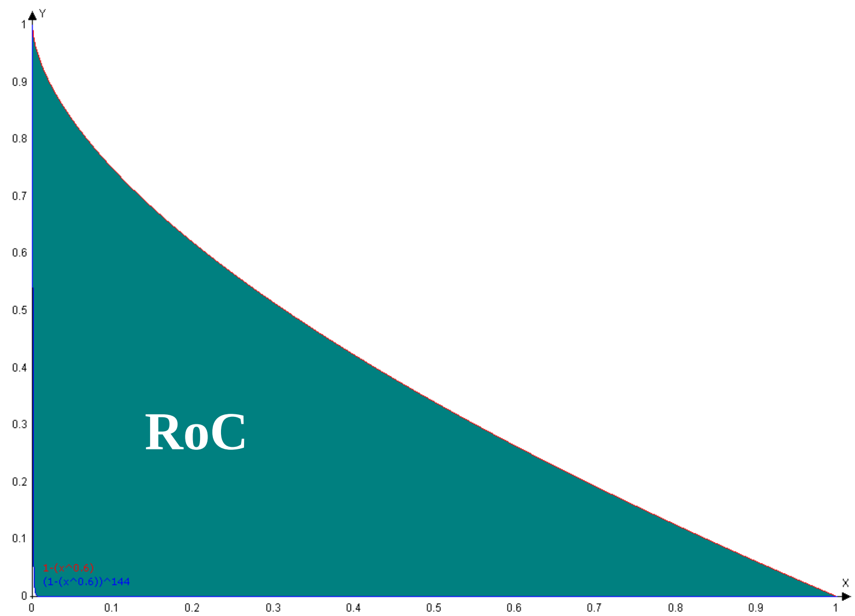

Figure 13-12: RoC End Pulse Width (n=144)

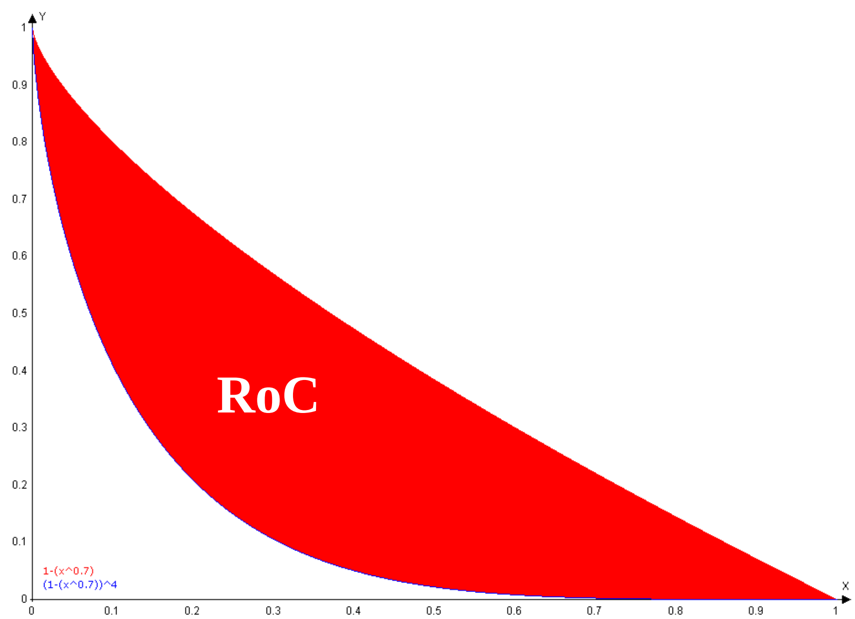

Figure 13-13: RoC Wakeup Pulse Width Factor (n=4)

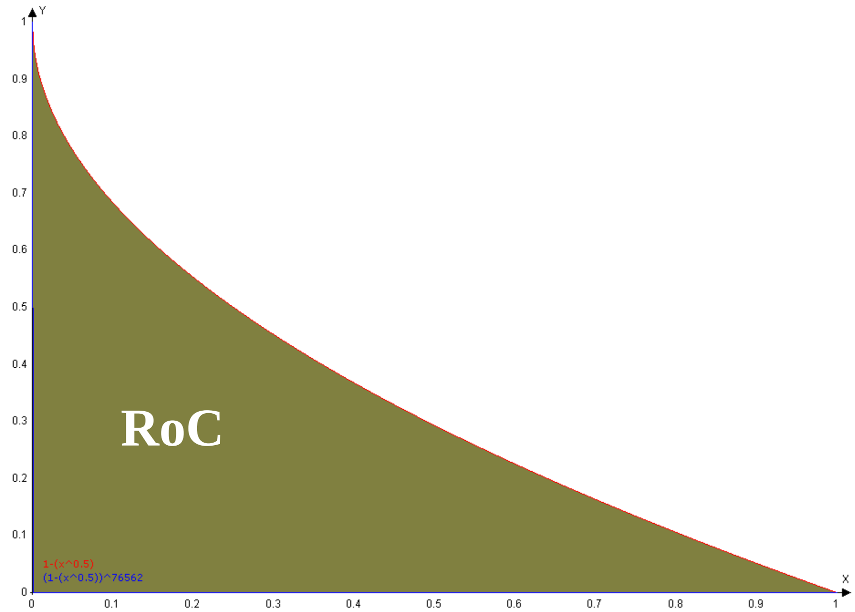

Figure 13-14: RoC Wakeup Length Factor (n=76562)

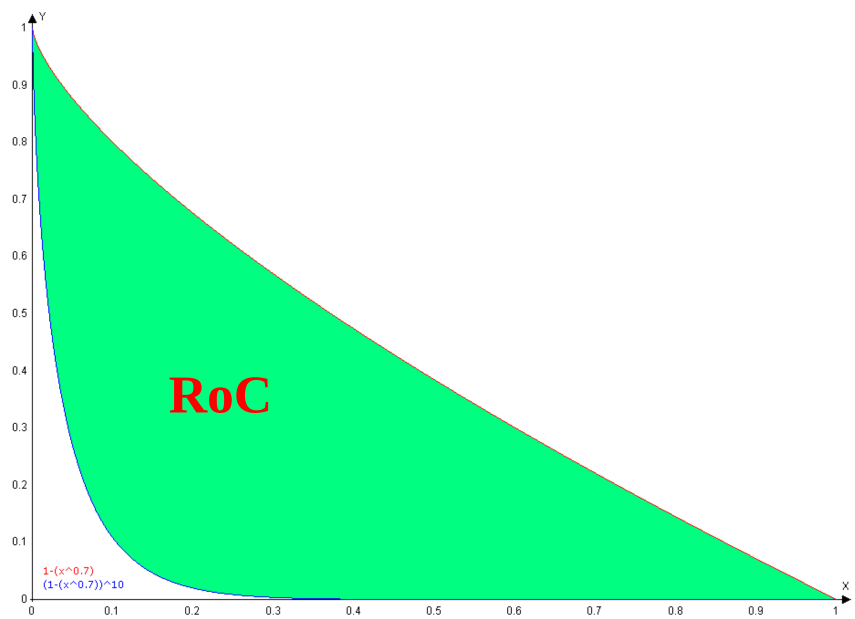

Figure 13-15: RoC of Co-Header Pulse Width Factor (n=10)

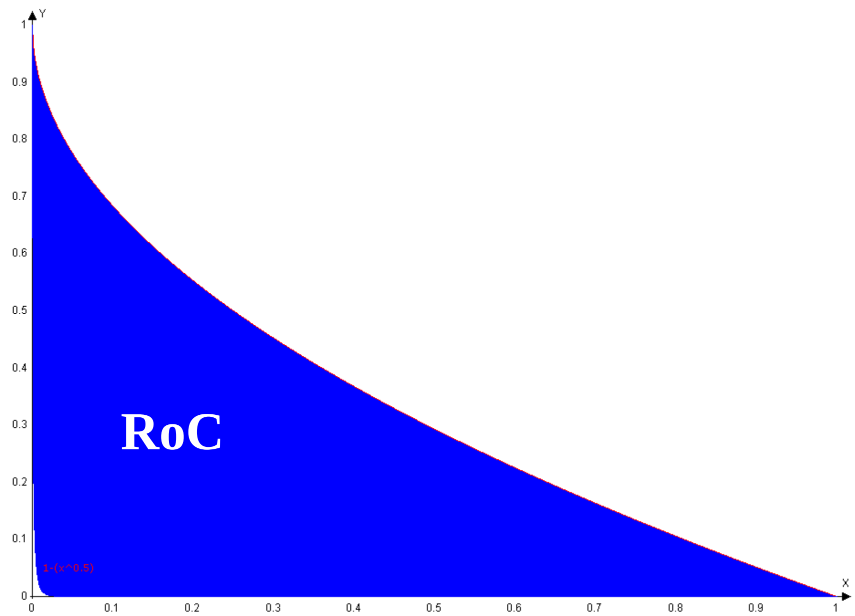

Figure 13-16: RoC Co-Header length Factor (n=40)

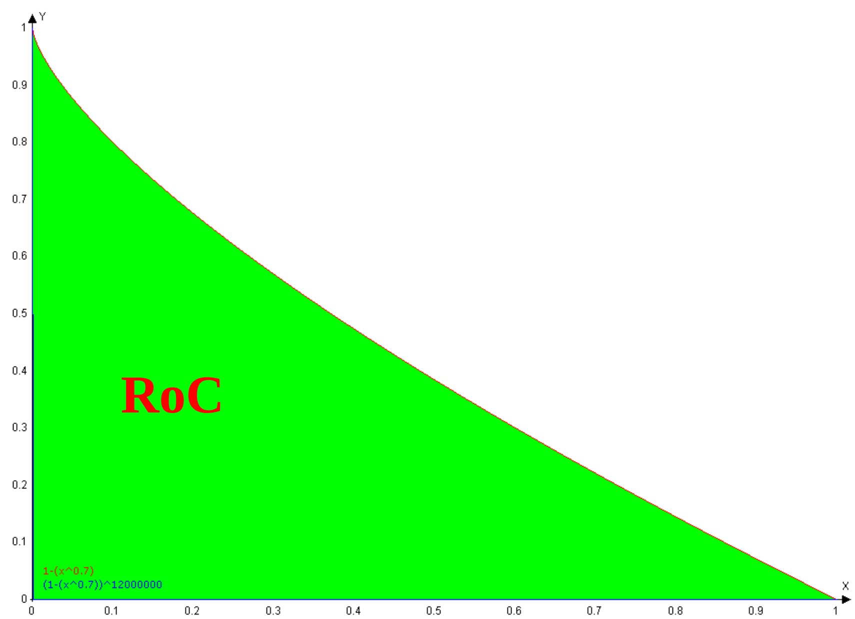

Figure 13-17: Time between Wakeup & Co-Header (n=12000000)

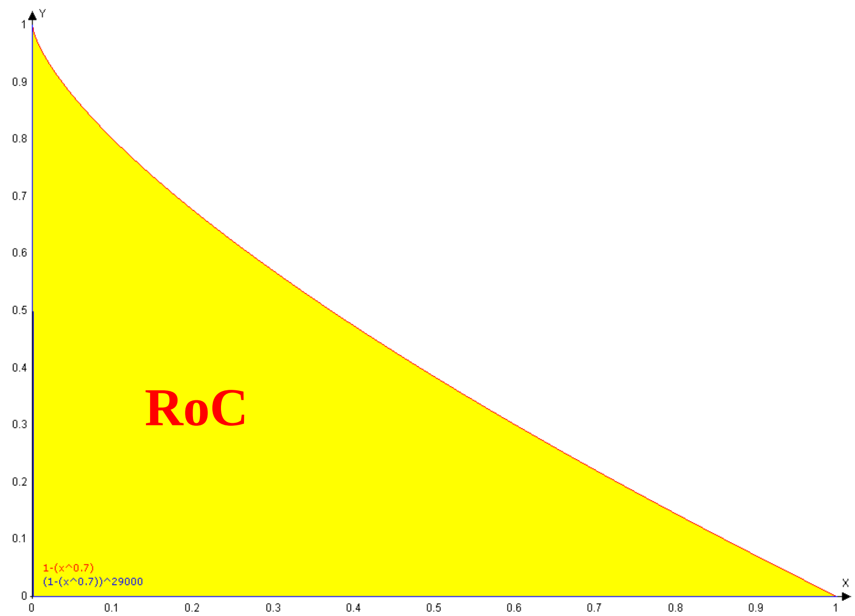

Figure 13-18: RoC Time between Wakeup & Command (n=29000)

13.3 TIME OF EXPERIMENT

Table 13-1 tabulates the time taken to execute the experiment for different values of LTPD when Beta is constant at 0.05.

Figure 13-19 shows the graphical representation of time of experiment versus LTPD when Beta is constant at 0.05.

Table 13-1: LTPD vs Time of Experiment for Beta =0.05

LTPD	Total Runs	Time of Experiment (hrs)	
0.02	524	7.27	Note 1
0.05	334	4.63	Note 2
0.08	259	3.6	Note 2
0.1	234	3.25	Note 2
0.15	163	2.26	Note 3
0.2	133	1.85	Note 3

Note 1: LTPD is too small to satisfy FSK, Data Pulse Width, Wakeup Pulse Width & Co-Header Pulse Width

Note 2: LTPD is too small to satisfy FSK, Wakeup Pulse Width & Co-Header Pulse Width

Note 3: LTPD is too small to satisfy Wakeup Pulse Width

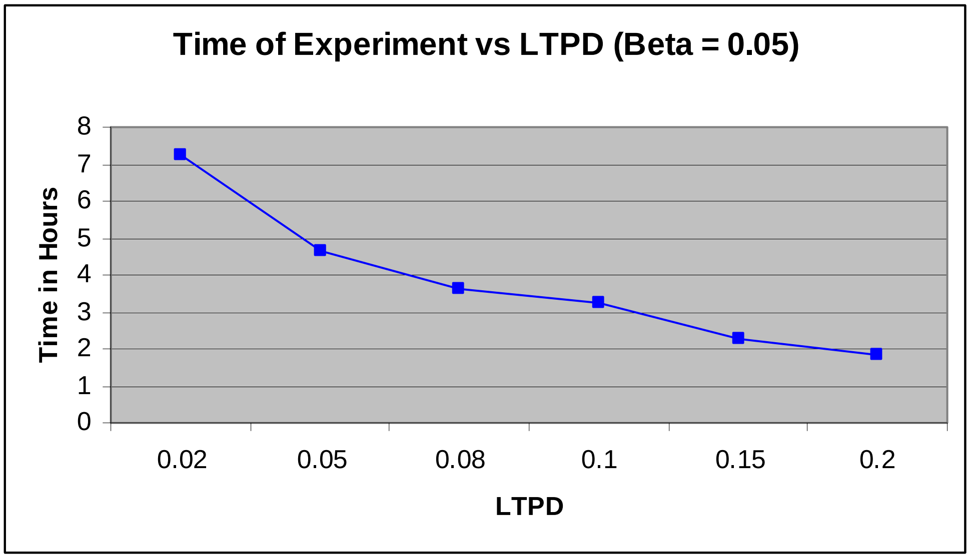

Figure 13-19: Time of Experiment vs LTPD for Beta = 0.05

Table 13-2 tabulates the time taken to execute the experiment for different values of LTPD when Beta is constant at 0.05.

Figure 13-20 shows the graphical representation of time of experiment versus LTPD when Beta is constant at 0.07.

Table 13-2: LTPD vs Time of Experiment for Beta = 0.07

LTPD	Total Runs	Time of Experiment (hrs)	
0.02	477	6.625	Note 1
0.05	315	4.375	Note 2
0.08	241	3.35	Note 2
0.1	200	2.78	Note 3
0.15	143	1.99	Note 4
0.2	105	1.46	Note 4

Note 1: LTPD is too small to satisfy FSK, Data Pulse Width, Wakeup Pulse Width & Co-Header Pulse Width

Note 2: LTPD is too small to satisfy FSK, Wakeup Pulse Width & Co-Header Pulse Width

Note 3: LTPD is too small to satisfy Wakeup Pulse Width & Co-Header Pulse Width

Note 4: LTPD is too small to satisfy Wakeup Pulse Width

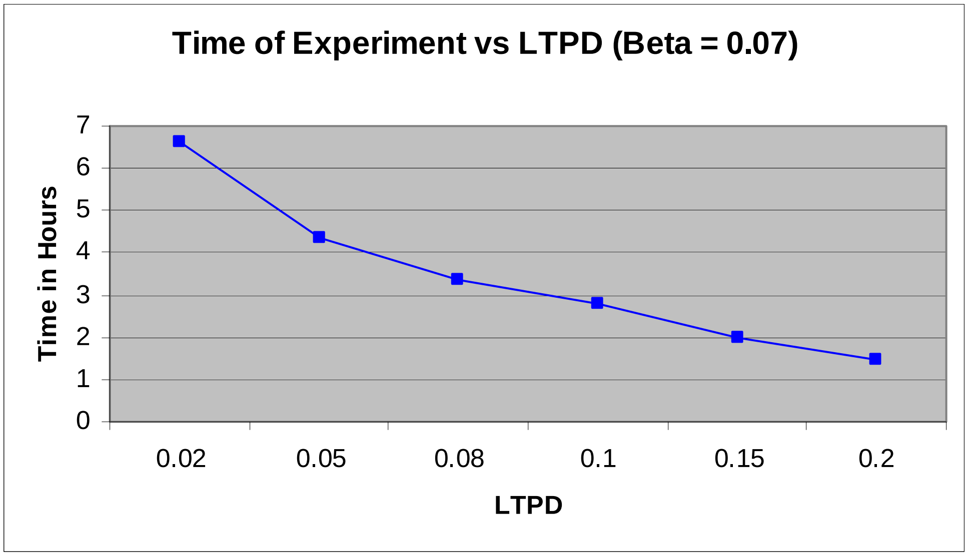

Figure 13-20: Time of Experiment vs LTPD for Beta = 0.07

Table 13-3 tabulates the time taken to execute the experiment for different values of LTPD when Beta is constant at 0.05.

Figure 13-21 shows the graphical representation of time of experiment versus LTPD when Beta is constant at 0.07.

Table 13-3: LTPD vs Time of Experiment for Beta = 0.1

LTPD	Total Runs	Time of Experiment (hrs)	
0.02	429	5.96	Note 1
0.05	272	3.78	Note 2
0.08	206	2.86	Note 2
0.1	182	2.53	Note 3
0.15	119	1.65	Note 4
0.2	93	1.29	Note 4

Note 1: LTPD is too small to satisfy FSK, Data Pulse Width, Wakeup Pulse Width & Co-Header Pulse Width

Note 2: LTPD is too small to satisfy FSK, Wakeup Pulse Width & Co-Header Pulse Width

Note 3: LTPD is too small to satisfy Wakeup Pulse Width & Co-Header Pulse Width

Note 4: LTPD is too small to satisfy Wakeup Pulse Width

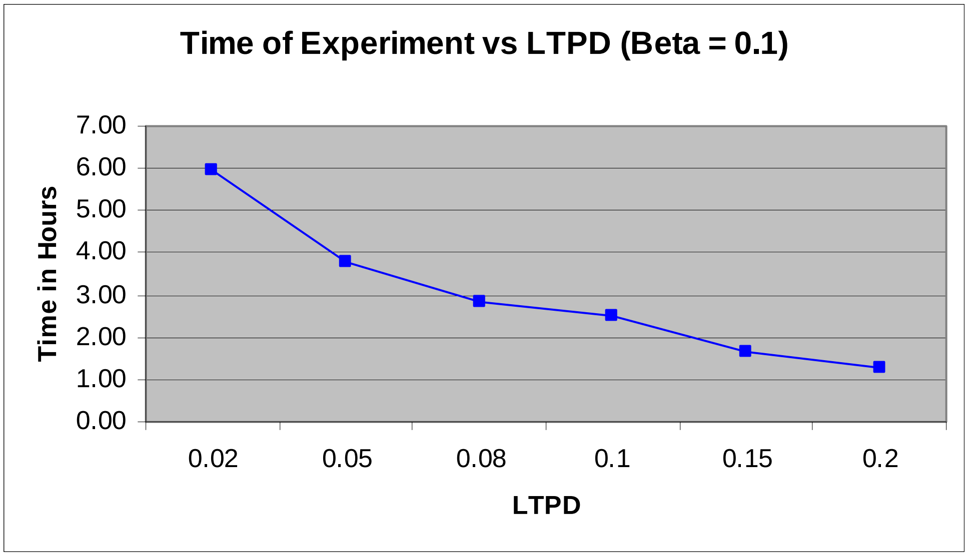

Figure 13-21: Time of Experiment vs LTPD for Beta = 0.1

13.4 INTEROPERABILITY TEST RESULTS ON A COMMERCIAL TAG

The summary of results of testing a commercial tag using the *Interoperability test Suite* software is presented below. The detailed report format of the interoperability test can be referred in Appendix B (Page 363).

Minimum Number of Preambles: *Interoperable*. Tag Under Test accepts the Minimum number of Preambles Transmitted

Transition Times: *Interoperable*. Tag Under Test accepts the Transition Times Transmitted

Wakeup Length: *Interoperable*. With confidence level of 95 % the error in interoperability property of the factor is < 5 %

CoHeader Length: *Interoperable*. With confidence level of 95 % the error in interoperability property of the factor is < 5 %

Time bet. Wakeup & CoHeader: *Interoperable*. With confidence level of 95 % the error in interoperability property of the factor is < 5 %

Time bet. Wakeup & Command: *Interoperable*. With confidence level of 95 % the error in interoperability property of the factor is < 5 %

Tag Awake Time: *Interoperable*. With confidence level of 95 % the error in interoperability property of the factor is < 5 %

Wakeup Pulse Width: *Interoperable*. With confidence level of 95 % the error in interoperability property of the factor is < 40 %

CoHeader Pulse Width: *Interoperable*. With confidence level of 95 % the error in interoperability property of the factor is < 15 %

Commands Supported: *Interoperable*. Tag Under Test responds to all Commands Transmitted

Preamble Pulse Width: *Interoperable*. With confidence level of 95 % the error in interoperability property of the factor is < 5 %

Sync Pulse Width: *Interoperable*. With confidence level of 95 % the error in interoperability property of the factor is < 5 %

Data Pulse Width: *Interoperable*. With confidence level of 95 % the error in interoperability property of the factor is < 5 %

End Pulse Width: *Interoperable*. With confidence level of 95 % the error in interoperability property of the factor is < 5 %

Initialization Pulse: *Interoperable*. Tag Under Test responds to commands transmitted with the Initialization Pulse

Termination Pulse: *Interoperable*. Tag Under Test responds to commands transmitted with the Termination Pulse

FSK Deviation: *Interoperable*. With confidence level of 95 % the error in interoperability property of the factor is < 11 %

Carrier: *Interoperable*. With confidence level of 95 % the error in interoperability property of the factor is < 5 %

Figure 13-22: Summary of Interoperability Test Result

In this case, because all the factors are satisfactorily interoperable, the test is a *PASS* and the tag is considered interoperable.

Figure 13-23 displays the front panel of the Interoperability Test Suite software after completion of the test. After the test is complete the progress bar is at 100% and if all the factors pass the test the green LED is *ON*. If one or more factors fail the red LED is *ON*. The values at which the tag fails to respond as required can be obtained from the *log file* or from the *Info* section

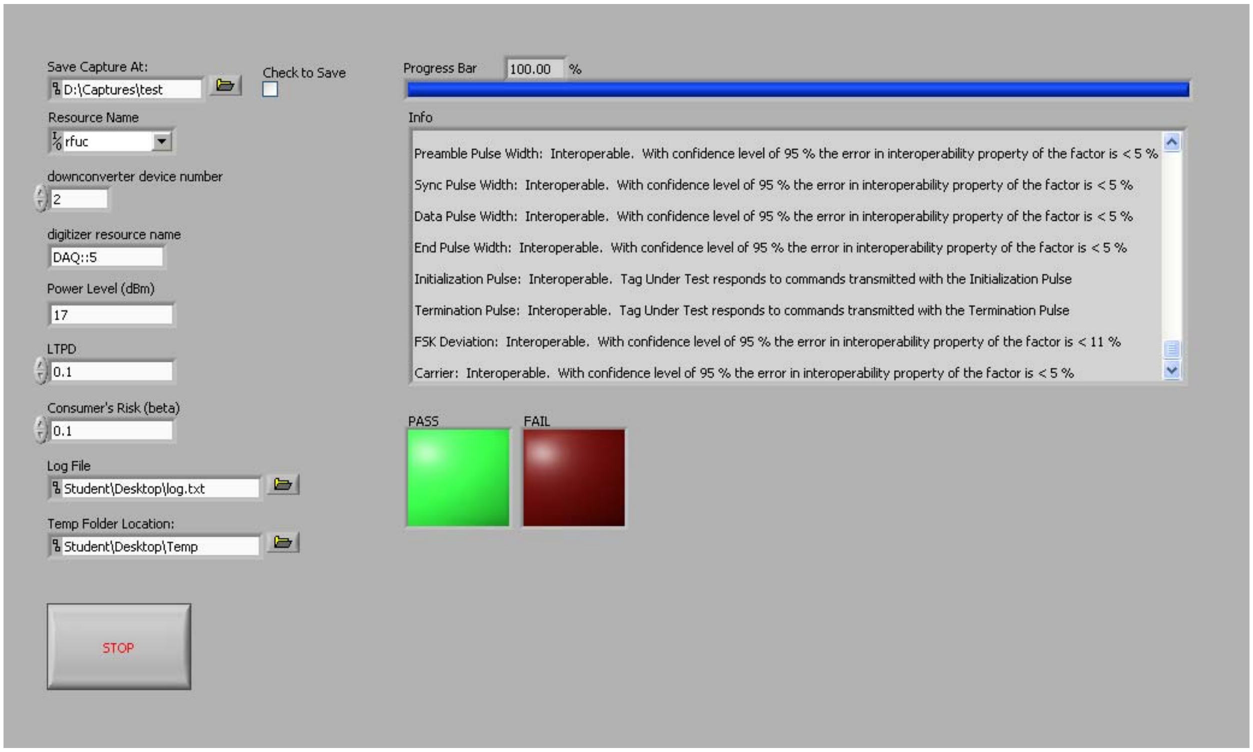

Figure 13-23: Front Panel of Interoperability Test Suite after completion of test.

13.5 GENERAL INTEROPERABILITY TEST PROCEDURE

The interoperability test methodology that is proposed in this research is implemented to develop an automated test solution which is used to analyze the interoperability property of commercial active tags and document the results. This methodology is not limited to a particular standard but intended to be applicable to all communications standards in practice built over the basic command-reply protocol. This section explains the essence of the research, breaking it into fundamental steps to be followed when adapting the current methodology to different standards.

The general steps in developing the interoperability test to a standard are:

1. Determine all factors that affect interoperability property of the entire communication system.
2. Separate dependent and independent factors using the ANOVA method.
3. Select an RFSG and research the best possible resolution of each factor.
4. Design the RFSG to transmit signals where the value of different factors is programmable within the standard.
5. Test if the DUT can accept each factor (or group of factors) at different discrete values within the range specified by the standard where the number of discrete values depends on the confidence level requirements of the test and the AoZ sampling calculations.
6. Normalization can be introduced into the test procedure.
7. Document findings and present results for each factor with an associated confidence level.

14.0 CONCLUSION

Interoperability, an essential property in all modern electronics, is loosing its importance and place in the design process. This incomplete design process can be attributed to lack of interoperability definitions and test procedures.

In this research, a new and innovative method to test interoperability among active RFID is developed. This method is not only limited to testing interoperability in active RFID but has the potential to revolutionize interoperability verification process among all wireless devices communicating via a command – reply protocol. The fundamental purpose of this research is an initiation and its validation to officially document interoperability definition, requirement, specifications and its verification among active RFID and later all wireless devices.

The major contribution of this thesis is towards analyzing the current ISO 18000-7 active RFID standard to understand its shortcomings to promote interoperable products and possible fixes to the problem. The different factors affecting interoperability in active RFID are recognized and the interaction among them has been researched.

Complex commercial RF test equipment, selected after careful research from many types of commercial test equipment, is used in this research to demonstrate the practicality of the interoperability test methodology. Intricate algorithms are developed to automate the entire testing process, significantly reducing the test time compared to manual testing which in this case is practically not feasible.

Implementable and efficient schemes are introduced into the test methodology to benefit from previous test experience of active RFID equipment to increase the efficiency and effectiveness of the interoperability test while significantly decreasing the time of the experiment.

The developed procedures will assist in planning the development process of the RF device and also help alter it where and when necessary while not only obeying the standard but also understanding the ultimate essence of it.

14.1 CONTRIBUTION OF THE RESEARCH

- ✓ The ISO 18000-7 standard and commercial active RFID systems have been researched to determine a total of over 40 factors that affect interoperability property.
- ✓ The analysis of variance technique was employed between two factors for all possible combinations to separate dependent and independent factors.
- ✓ A commercial signal generator from NI, the ni5671 has been selected for the research and it is programmed using LabView to emulate a conforming active RFID reader (also called GOLD standard Reader for Active RFID).
- ✓ The resolution of different factors (the maximum number of unique values of each factor that can be tested) that can be achieved using the ni5671 has been determined and the signal generator is programmed accordingly.
- ✓ Using Accept on Zero sampling technique, each factor was tested at unique values to deduce with a confidence the percentage of error in the interoperability property of that factor.
- ✓ An innovative normalization concept is introduced into the test methodology to benefit from the experience gained from previous conformance tests and observations. The time of experiment is significantly reduced making the test more efficient.
- ✓ An automated test is designed where with minimum human supervision; any commercial active tag can be tested for interoperability as per ISO 18000-7. The results are presented in detail and in simple boolean visual form.

- ✓ Different commercial tags have been tested. Some of them were found to be sufficiently interoperable.

The technique and methodology of single unit interoperability testing has been demonstrated.

15.0 FUTURE WORK

The methodology and Interoperability test software controlling the GOLD programmable reader developed in this thesis to test the interoperability property of active tags can be extended to test an active reader. As already explained in section 11.0 , designing a GOLD active tag with the same functionality of the current GOLD programmable reader is more challenging. The real-time processing of RF data can be achieved by introducing the ni5640R into the test setup, which is a programmable FPGA module from National Instruments that is specifically designed to interact with both the RFSA and RFSG from NI and is programmable through Labview like all other NI hardware.

The next evolution in the development of the interoperability test is to perform research on other commercially available RF signal generators from Tektronix, HP, Agilent and also the latest from National Instruments (like ni5672 and ni5673) to increase the possible sample size in each factor affecting interoperability. The current resolution and the corresponding maximum sample size of all factors in this experiment setup using ni5671 are tabulated in Table 10-4 and Table 10-23.

There are three primary modules that limit the sample size of factors (and in turn the confident level of the experiment) in the current experimental setup not considering the extent of programmability provided by the commercial equipment to the user. The three modules are: IQ Sampling Rates, Memory and Data Transfer Rates between RFSG and PC. Obviously, higher the IQ sampling rates supported by the RFSG the more samples all the pulse width factors can be tested at. Even if the hardware supports a very high IQ sampling rate, it may not be possible to join two already modulated signals of different fundamental frequency due to phase discontinuity. This problem can be solved if the entire sequence to be transmitted (2.4 seconds of wakeup immediately followed by 100ms of co-header) can be samples at a very high IQ rate and modulated all at once and stored in the RFSG memory. But the wakeup sequence sampled at 100M samples per second will require approximately 2GB of memory on the RFSG. This amount of memory is not typically installed or supported by commercial RFSGs. Modern signal generators like the ni5673 claim to support high IQ sampling rates and transmit modulated waveforms stored on the PC hard disk. This is a possible solution to the problem. Also the PC should have the necessary requirements (RAM, Processor Speed and HD memory) to build the IQ data before transmitting to the RFSG. As mentioned before the wakeup sequence requires a memory space of 2GB. This data is processed and copied by the LabView software while in baseband stage and modulation stage. The PC should be able to handle the data requirements. The generated IQ data for wakeup sequence has to be transferred to the RFSG for continuous transmission. A typical PXI cable may not have the sufficient band width for this application. NI has developed express PXI cards that can support data transfer rates up to 2GB/s.

The final frontier of this research is to adapt the methodology in this thesis to other standards. The primary areas of concentration will be other RFID standards like the ISO 18000-6c for passive UHF RFID and ISO 18000-3 for passive HF tags.

APPENDIX A

ANALYSIS OF VARIANCE OF FACTORS – RESULTS

In this section, the detailed analysis of all factors to determine any dependency using ANOVA technique is provided for reference.

Each ANOVA table is divided into three sections. The first section gathers data varying one factor and recording the changes in the other factor.

The second section is the *SUMMARY* section. In this section the sum, average and variance of the output data gathered before is calculated.

The final and third section is the *ANOVA* section. Here analysis of variance is performed on the two factors and summarized.

If the ANOVA between any two factors is not displayed in this document, it is because there is no variation observed in the output data.

A.1 CARRIER VS.

Table A-1: Carrier vs. Maximum FSK Deviation ANOVA

	Max. FSK Deviation (kHz)					
Carrier Frequency (MHz)	1	2	3	4		
433.88	90	85	90	90		
433.89	95	95	90	90		
433.9	100	100	100	95		
433.91	95	90	90	95		
433.92	80	80	80	80		
433.93	70	70	70	70		
433.94	60	65	60	60		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	355	88.75	6.25		
Row 2	4	370	92.5	8.333333		
Row 3	4	395	98.75	6.25		
Row 4	4	370	92.5	8.333333		
Row 5	4	320	80	0		
Row 6	4	280	70	0		
Row 7	4	245	61.25	6.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4446.429	6	741.0714	146.4706	5.04E-16	2.572712
Within Groups	106.25	21	5.059524			
Total	4552.679	27				

Table A-2: Carrier vs. Minimum FSK Deviation ANOVA

	Min. FSK Deviation					
Carrier Frequency (MHz)	1	2	3	4		
433.88	20	20	25	20		
433.89	15	15	15	15		
433.9	15	15	20	20		
433.91	15	20	15	15		
433.92	15	20	20	20		
433.93	15	10	15	10		
433.94	15	15	15	15		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	85	21.25	6.25		
Row 2	4	60	15	0		
Row 3	4	70	17.5	8.333333		
Row 4	4	65	16.25	6.25		
Row 5	4	75	18.75	6.25		
Row 6	4	50	12.5	8.333333		
Row 7	4	60	15	0		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	196.4286	6	32.7381	6.470588	0.00056	2.572712
Within Groups	106.25	21	5.059524			
Total	302.6786	27				

Table A-3: Carrier vs. Maximum Wakeup Pulse Width ANOVA

	Max. Wakeup Pulse Width (us)					
Carrier Frequency (MHz)	1	2	3	4		
433.88	17	17	19	17		
433.89	18	18	17	18		
433.9	18	17	19	19		
433.91	17	17	18	17		
433.92	17	19	17	18		
433.93	18	17	18	18		
433.94	19	17	17	17		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	70	17.5	1		
Row 2	4	71	17.75	0.25		
Row 3	4	73	18.25	0.916667		
Row 4	4	69	17.25	0.25		
Row 5	4	71	17.75	0.916667		
Row 6	4	71	17.75	0.25		
Row 7	4	70	17.5	1		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.357143	6	0.392857	0.6	0.727166	2.572712
Within Groups	13.75	21	0.654762			
Total	16.10714	27				

Table A-4: Carrier vs. Minimum Wakeup Pulse Width ANOVA

	Min. Wakeup Pulse Width (us)					
Carrier Frequency (MHz)	1	2	3	4		
433.88	14	15	14	14		
433.89	14	15	15	15		
433.9	15	14	14	14		
433.91	14	15	14	15		
433.92	15	14	14	14		
433.93	14	14	14	14		
433.94	14	14	15	15		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	57	14.25	0.25		
Row 2	4	59	14.75	0.25		
Row 3	4	57	14.25	0.25		
Row 4	4	58	14.5	0.333333		
Row 5	4	57	14.25	0.25		
Row 6	4	56	14	0		
Row 7	4	58	14.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.428571	6	0.238095	1	0.451174	2.572712
Within Groups	5	21	0.238095			
Total	6.428571	27				

Table A-5: Carrier vs. Maximum CoHeader Pulse Width ANOVA

	Max. CoHeader Pulse Width (us)					
Carrier Frequency (MHz)	1	2	3	4		
433.88	55	56	55	55		
433.89	56	55	56	56		
433.9	55	55	55	55		
433.91	55	56	55	55		
433.92	55	56	55	56		
433.93	56	55	56	55		
433.94	56	55	56	55		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	221	55.25	0.25		
Row 2	4	223	55.75	0.25		
Row 3	4	220	55	0		
Row 4	4	221	55.25	0.25		
Row 5	4	222	55.5	0.333333		
Row 6	4	222	55.5	0.333333		
Row 7	4	222	55.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.428571	6	0.238095	0.952381	0.480017	2.572712
Within Groups	5.25	21	0.25			
Total	6.678571	27				

Table A-6: Carrier vs. Minimum CoHeader Pulse Width ANOVA

	Min. CoHeader Pulse Width (us)			
Carrier Frequency (MHz)	1	2	3	4
433.88	47	48	47	47
433.89	48	47	47	48
433.9	47	48	47	48
433.91	48	47	47	47
433.92	47	47	47	48
433.93	48	47	48	47
433.94	47	48	48	47
SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	189	47.25	0.25
Row 2	4	190	47.5	0.333333
Row 3	4	190	47.5	0.333333
Row 4	4	189	47.25	0.25
Row 5	4	189	47.25	0.25
Row 6	4	190	47.5	0.333333
Row 7	4	190	47.5	0.333333

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.428571	6	0.071429	0.24	0.958099	2.572712
Within Groups	6.25	21	0.297619			
Total	6.678571	27				

Table A-7: Carrier vs. Maximum Preamble Pulse Width ANOVA

	Max. Preamble Width			
Carrier Frequency (MHz)	1	2	3	4
433.88	67	66	67	65
433.89	67	65	67	66
433.9	67	66	67	66
433.91	67	67	67	66
433.92	65	67	67	67
433.93	67	66	65	67
433.94	67	65	66	66
SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	265	66.25	0.916667
Row 2	4	265	66.25	0.916667
Row 3	4	266	66.5	0.333333
Row 4	4	267	66.75	0.25
Row 5	4	266	66.5	1
Row 6	4	265	66.25	0.916667
Row 7	4	264	66	0.666667

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.428571	6	0.238095	0.333333	0.911652	2.572712
Within Groups	15	21	0.714286			
Total	16.42857	27				

Table A-8: Carrier vs. Minimum Preamble Pulse Width ANOVA

	Min. Preamble Width					
Carrier Frequency (MHz)	1	2	3	4		
433.88	55	54	55	55		
433.89	55	54	55	54		
433.9	55	55	55	55		
433.91	55	54	54	55		
433.92	55	55	55	55		
433.93	54	55	54	55		
433.94	54	55	55	54		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	219	54.75	0.25		
Row 2	4	218	54.5	0.333333		
Row 3	4	220	55	0		
Row 4	4	218	54.5	0.333333		
Row 5	4	220	55	0		
Row 6	4	218	54.5	0.333333		
Row 7	4	218	54.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.357143	6	0.22619	1	0.451174	2.572712
Within Groups	4.75	21	0.22619			
Total	6.107143	27				

Table A-9: Carrier vs. Maximum Sync Pulse Width ANOVA

	Max. Sync Width					
Carrier Frequency (MHz)	1	2	3	4		
433.88	57	56	56	56		
433.89	56	56	56	57		
433.9	57	57	56	56		
433.91	57	56	56	56		
433.92	56	56	56	56		
433.93	56	56	57	56		
433.94	57	56	56	56		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	225	56.25	0.25		
Row 2	4	225	56.25	0.25		
Row 3	4	226	56.5	0.333333		
Row 4	4	225	56.25	0.25		
Row 5	4	224	56	0		
Row 6	4	225	56.25	0.25		
Row 7	4	225	56.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.5	6	0.083333	0.368421	0.890727	2.572712
Within Groups	4.75	21	0.22619			
Total	5.25	27				

Table A-10: Carrier vs. Minimum Sync Pulse Width ANOVA

	Min. Sync Width			
Carrier Frequency (MHz)	1	2	3	4
433.88	51	52	51	51
433.89	52	51	51	52
433.9	52	51	52	52
433.91	51	52	52	51
433.92	52	52	51	52
433.93	51	51	52	52
433.94	52	52	52	51
SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	205	51.25	0.25
Row 2	4	206	51.5	0.333333
Row 3	4	207	51.75	0.25
Row 4	4	206	51.5	0.333333
Row 5	4	207	51.75	0.25
Row 6	4	206	51.5	0.333333
Row 7	4	207	51.75	0.25

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.857143	6	0.142857	0.5	0.801217	2.572712
Within Groups	6	21	0.285714			
Total	6.857143	27				

Table A-11: Carrier vs. Maximum Data Pulse Width ANOVA

	Max. Data Width (us)					
Carrier Frequency (MHz)	1	2	3	4		
433.88	40	40	40	39		
433.89	39	40	40	40		
433.9	40	39	40	39		
433.91	40	40	39	40		
433.92	39	40	39	40		
433.93	40	40	40	40		
433.94	39	40	39	39		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	159	39.75	0.25		
Row 2	4	159	39.75	0.25		
Row 3	4	158	39.5	0.333333		
Row 4	4	159	39.75	0.25		
Row 5	4	158	39.5	0.333333		
Row 6	4	160	40	0		
Row 7	4	157	39.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.428571	6	0.238095	1	0.451174	2.572712
Within Groups	5	21	0.238095			
Total	6.428571	27				

Table A-12: Carrier vs. Minimum Data Pulse Width ANOVA

	Min. Data Width			
Carrier Frequency (MHz)	1	2	3	4
433.88	31	30	31	30
433.89	30	31	30	30
433.9	31	30	30	31
433.91	30	30	31	31
433.92	30	31	30	30
433.93	31	30	30	30
433.94	30	30	30	31
SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	122	30.5	0.333333
Row 2	4	121	30.25	0.25
Row 3	4	122	30.5	0.333333
Row 4	4	122	30.5	0.333333
Row 5	4	121	30.25	0.25
Row 6	4	121	30.25	0.25
Row 7	4	121	30.25	0.25

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.428571	6	0.071429	0.25	0.95386	2.572712
Within Groups	6	21	0.285714			
Total	6.428571	27				

Table A-13: Carrier vs. Maximum End Pulse Width ANOVA

	Max. End Pulse Width (us)			
Carrier Frequency (MHz)	1	2	3	4
433.88	45	45	45	45
433.89	45	45	45	45
433.9	45	45	45	45
433.91	45	45	45	45
433.92	45	45	45	45
433.93	45	45	45	45
433.94	45	45	45	45
SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	180	45	0
Row 2	4	180	45	0
Row 3	4	180	45	0
Row 4	4	180	45	0
Row 5	4	180	45	0
Row 6	4	180	45	0
Row 7	4	180	45	0

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0	6	0	65535	#NUM!	2.572712
Within Groups	0	21	0			
Total	0	27				

Table A-14: Carrier vs. Minimum End Pulse Width ANOVA

	Min. End Pulse Width (us)			
Carrier Frequency (MHz)	1	2	3	4
433.88	0	0	0	0
433.89	0	0	0	0
433.9	0	0	0	0
433.91	0	0	0	0
433.92	0	0	0	0
433.93	0	0	0	0
433.94	0	0	0	0

No variation in result data. Hence Independent.

Table A-15: Carrier vs. Maximum Initialization Pulse Width ANOVA

	Max. Initialization Pulse Width (us)			
Carrier Frequency (MHz)	1	2	3	4
433.88	20	20	20	20
433.89	20	20	20	20
433.9	20	20	20	20
433.91	20	20	20	20
433.92	20	20	20	20
433.93	20	20	20	20
433.94	20	20	20	20

No variation in result data. Hence Independent.

Table A-16: Carrier vs. Minimum Initialization Pulse Width ANOVA

	Min. Initialization Pulse Width (us)			
Carrier Frequency (MHz)	1	2	3	4
433.88	0	0	0	0
433.89	0	0	0	0
433.9	0	0	0	0
433.91	0	0	0	0
433.92	0	0	0	0
433.93	0	0	0	0
433.94	0	0	0	0

No variation in result data. Hence Independent.

Table A-17: Carrier vs. Maximum Termination Pulse Width ANOVA

	Max. Termination Pulse Width (us)			
Carrier Frequency (MHz)	1	2	3	4
433.88	20	20	20	20
433.89	20	20	20	20
433.9	20	20	20	20
433.91	20	20	20	20
433.92	20	20	20	20
433.93	20	20	20	20
433.94	20	20	20	20

No variation in result data. Hence Independent.

Table A-18: Carrier vs. Minimum Termination Pulse Width ANOVA

	Min. Termination Pulse Width (us)			
Carrier Frequency (MHz)	1	2	3	4
433.88	0	0	0	0
433.89	0	0	0	0
433.9	0	0	0	0
433.91	0	0	0	0
433.92	0	0	0	0
433.93	0	0	0	0
433.94	0	0	0	0

No variation in result data. Hence Independent.

Table A-19: Carrier vs. Maximum Wakeup Length ANOVA

	Max. Wakeup (sec)			
Carrier Frequency (MHz)	1	2	3	4
433.88	4.8	4.8	4.8	4.8
433.89	4.8	4.8	4.8	4.8
433.9	4.8	4.8	4.8	4.8
433.91	4.8	4.8	4.8	4.8
433.92	4.8	4.8	4.8	4.8
433.93	4.8	4.8	4.8	4.8
433.94	4.8	4.8	4.8	4.8

No variation in result data. Hence Independent.

Table A-20: Carrier vs. Minimum Wakeup Length ANOVA

	Min. Wakeup (sec)			
Carrier Frequency (MHz)	1	2	3	4
433.88	0.8	0.8	0.8	0.8
433.89	0.8	0.8	0.8	0.8
433.9	0.8	0.8	0.8	0.8
433.91	0.8	0.8	0.8	0.8
433.92	0.8	0.8	0.8	0.8
433.93	0.8	0.8	0.8	0.8
433.94	0.8	0.8	0.8	0.8

No variation in result data. Hence Independent.

Table A-21: Carrier vs. Maximum CoHeader Length ANOVA

	Max. CoHeader			
Carrier Frequency (MHz)	1	2	3	4
433.88	5000	5000	5000	5000
433.89	5000	5000	5000	5000
433.9	5000	5000	5000	5000
433.91	5000	5000	5000	5000
433.92	5000	5000	5000	5000
433.93	5000	5000	5000	5000
433.94	5000	5000	5000	5000

No variation in result data. Hence Independent.

Table A-22: Carrier vs. Minimum CoHeader Length ANOVA

	Min. CoHeader (ms)			
Carrier Frequency (MHz)	1	2	3	4
433.88	2.5	2.5	2.5	2.5
433.89	2.5	2.5	2.5	2.5
433.9	2.5	2.5	2.5	2.5
433.91	2.5	2.5	2.5	2.5
433.92	2.5	2.5	2.5	2.5
433.93	2.5	2.5	2.5	2.5
433.94	2.5	2.5	2.5	2.5

No variation in result data. Hence Independent.

Table A-23: Carrier vs. Maximum Time between Wakeup & CoHeader ANOVA

	Max. Time bet Wakeup & CoHeader (us)			
Carrier Frequency (MHz)	1	2	3	4
433.88	800	800	800	800
433.89	800	800	800	800
433.9	800	800	800	800
433.91	800	800	800	800
433.92	800	800	800	800
433.93	800	800	800	800
433.94	800	800	800	800

No variation in result data. Hence Independent.

Table A-24: Carrier vs. Minimum Time between Wakeup & CoHeader ANOVA

	Min. Time bet Wakeup & CoHeader (us)			
Carrier Frequency (MHz)	1	2	3	4
433.88	0	0	0	0
433.89	0	0	0	0
433.9	0	0	0	0
433.91	0	0	0	0
433.92	0	0	0	0
433.93	0	0	0	0
433.94	0	0	0	0

No variation in result data. Hence Independent.

Table A-25: Carrier vs. Maximum Time between Wakeup & Command ANOVA

	Max. Time bet Wakeup & Command					
Carrier Frequency (MHz)	1	2	3	4		
433.88	28	29	28	28		
433.89	29	29	29	29		
433.9	28	29	29	28		
433.91	29	29	28	28		
433.92	29	29	29	29		
433.93	28	28	29	29		
433.94	29	28	28	29		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	113	28.25	0.25		
Row 2	4	116	29	0		
Row 3	4	114	28.5	0.333333		
Row 4	4	114	28.5	0.333333		
Row 5	4	116	29	0		
Row 6	4	114	28.5	0.333333		
Row 7	4	114	28.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.928571	6	0.321429	1.421053	0.253251	2.572712
Within Groups	4.75	21	0.22619			
Total	6.678571	27				

Table A-26: Carrier vs. Minimum Time between Wakeup & Command ANOVA

	Min. Time bet Wakeup & Command (us)			
Carrier Frequency (MHz)	1	2	3	4
433.88	1	1	1	1
433.89	1	1	1	1
433.9	1	1	1	1
433.91	1	1	1	1
433.92	1	1	1	1
433.93	1	1	1	1
433.94	1	1	1	1

No variation in result data. Hence Independent.

Table A-27: Carrier vs. Tag Awake Time ANOVA

	Tag Awake Time (sec)					
Carrier Frequency (MHz)	1	2	3	4		
433.88	29	29	29	28		
433.89	28	29	29	28		
433.9	29	29	28	29		
433.91	28	29	29	29		
433.92	29	29	28	29		
433.93	29	28	29	29		
433.94	29	28	29	28		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	115	28.75	0.25		
Row 2	4	114	28.5	0.333333		
Row 3	4	115	28.75	0.25		
Row 4	4	115	28.75	0.25		
Row 5	4	115	28.75	0.25		
Row 6	4	115	28.75	0.25		
Row 7	4	114	28.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.357143	6	0.059524	0.217391	0.966953	2.572712
Within Groups	5.75	21	0.27381			
Total	6.107143	27				

Table A-28: Carrier vs. Minimum number of Preambles ANOVA

	Min. No. of Preambles					
Carrier Frequency (MHz)	1	2	3	4		
433.88	10	11	10	12		
433.89	12	12	11	12		
433.9	12	10	10	11		
433.91	12	11	10	10		
433.92	10	10	11	11		
433.93	10	12	10	11		
433.94	12	10	10	11		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	43	10.75	0.916667		
Row 2	4	47	11.75	0.25		
Row 3	4	43	10.75	0.916667		
Row 4	4	43	10.75	0.916667		
Row 5	4	42	10.5	0.333333		
Row 6	4	43	10.75	0.916667		
Row 7	4	43	10.75	0.916667		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.928571	6	0.654762	0.887097	0.521675	2.572712
Within Groups	15.5	21	0.738095			
Total	19.42857	27				

Table A-29: Carrier vs. Transition Time ANOVA

	Groups of Transitions Accepted			
Carrier Frequency (MHz)	1	2	3	4
433.88	8	8	8	8
433.89	8	8	8	8
433.9	8	8	8	8
433.91	8	8	8	8
433.92	8	8	8	8
433.93	8	8	8	8
433.94	8	8	8	8

No variation in result data. Hence Independent.

A.2 FSK DEVIATION VS.

Table A-30: FSK Deviation vs. Maximum Wakeup Pulse Width ANOVA

	Max. Wakeup Width (us)					
FSK Deviation (kHz)	1	2	3	4		
80	17	18	19	18		
75	18	18	17	18		
70	18	19	18	18		
65	19	17	18	18		
60	19	18	18	17		
55	17	18	18	18		
50	18	18	18	18		
45	19	17	19	19		
40	18	17	17	18		
35	19	18	18	19		
30	19	18	17	17		
25	18	18	18	18		
20	18	17	18	18		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	72	18	0.666667		
Row 2	4	71	17.75	0.25		
Row 3	4	73	18.25	0.25		
Row 4	4	72	18	0.666667		
Row 5	4	72	18	0.666667		
Row 6	4	71	17.75	0.25		
Row 7	4	72	18	0		
Row 8	4	74	18.5	1		
Row 9	4	70	17.5	0.333333		
Row 10	4	74	18.5	0.333333		
Row 11	4	71	17.75	0.916667		
Row 12	4	72	18	0		
Row 13	4	71	17.75	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4.230769	12	0.352564	0.820896	0.628411	2.010183
Within Groups	16.75	39	0.429487			
Total	20.98077	51				

Table A-31: FSK Deviation vs. Minimum Wakeup Pulse Width ANOVA

	Min. Wakeup Width (us)					
FSK Deviation (kHz)	1	2	3	4		
80	15	14	15	14		
75	14	15	14	14		
70	14	14	14	14		
65	14	15	15	14		
60	14	14	14	14		
55	15	14	15	14		
50	14	14	14	14		
45	15	14	14	15		
40	14	14	14	14		
35	14	15	14	15		
30	14	14	14	14		
25	14	15	14	14		
20	14	14	15	14		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	58	14.5	0.333333		
Row 2	4	57	14.25	0.25		
Row 3	4	56	14	0		
Row 4	4	58	14.5	0.333333		
Row 5	4	56	14	0		
Row 6	4	58	14.5	0.333333		
Row 7	4	56	14	0		
Row 8	4	58	14.5	0.333333		
Row 9	4	56	14	0		
Row 10	4	58	14.5	0.333333		
Row 11	4	56	14	0		
Row 12	4	57	14.25	0.25		
Row 13	4	57	14.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.5	12	0.208333	1.12069	0.371974	2.010183
Within Groups	7.25	39	0.185897			
Total	9.75	51				

Table A-32: FSK Deviation vs. Maximum Co-Header Pulse Width ANOVA

	Max. CoHeader Width (us)					
FSK Deviation (kHz)	1	2	3	4		
80	55	56	55	56		
75	56	55	56	55		
70	55	56	56	55		
65	56	55	55	56		
60	55	56	56	55		
55	55	56	55	56		
50	56	55	56	55		
45	55	56	55	55		
40	56	55	56	55		
35	55	56	55	56		
30	56	55	56	55		
25	55	56	55	55		
20	55	55	55	56		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	222	55.5	0.333333		
Row 2	4	222	55.5	0.333333		
Row 3	4	222	55.5	0.333333		
Row 4	4	222	55.5	0.333333		
Row 5	4	222	55.5	0.333333		
Row 6	4	222	55.5	0.333333		
Row 7	4	222	55.5	0.333333		
Row 8	4	221	55.25	0.25		
Row 9	4	222	55.5	0.333333		
Row 10	4	222	55.5	0.333333		
Row 11	4	222	55.5	0.333333		
Row 12	4	221	55.25	0.25		
Row 13	4	221	55.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.576923	12	0.048077	0.153061	0.999378	2.010183
Within Groups	12.25	39	0.314103			
Total	12.82692	51				

Table A-33: FSK Deviation vs. Minimum Co-Header Pulse Width ANOVA

	Min. CoHeader Width (us)					
FSK Deviation (kHz)	1	2	3	4		
80	47	48	47	47		
75	48	47	47	48		
70	47	48	47	48		
65	48	47	47	47		
60	47	47	48	48		
55	47	47	48	47		
50	47	48	47	48		
45	48	47	47	47		
40	48	48	48	48		
35	47	48	47	48		
30	48	47	48	48		
25	48	48	48	47		
20	47	48	47	48		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	189	47.25	0.25		
Row 2	4	190	47.5	0.333333		
Row 3	4	190	47.5	0.333333		
Row 4	4	189	47.25	0.25		
Row 5	4	190	47.5	0.333333		
Row 6	4	189	47.25	0.25		
Row 7	4	190	47.5	0.333333		
Row 8	4	189	47.25	0.25		
Row 9	4	192	48	0		
Row 10	4	190	47.5	0.333333		
Row 11	4	191	47.75	0.25		
Row 12	4	191	47.75	0.25		
Row 13	4	190	47.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.5	12	0.208333	0.77381	0.672794	2.010183
Within Groups	10.5	39	0.269231			
Total	13	51				

Table A-34: FSK Deviation vs. Maximum Preamble Pulse Width ANOVA

	Max. Preamble Width (us)					
FSK Deviation (kHz)	1	2	3	4		
80	67	67	66	67		
75	66	67	67	67		
70	67	66	67	66		
65	67	67	67	66		
60	66	67	66	67		
55	67	66	66	67		
50	67	67	66	67		
45	67	66	67	67		
40	66	66	67	67		
35	67	67	67	67		
30	66	67	66	66		
25	66	66	67	67		
20	67	66	67	66		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	267	66.75	0.25		
Row 2	4	267	66.75	0.25		
Row 3	4	266	66.5	0.333333		
Row 4	4	267	66.75	0.25		
Row 5	4	266	66.5	0.333333		
Row 6	4	266	66.5	0.333333		
Row 7	4	267	66.75	0.25		
Row 8	4	267	66.75	0.25		
Row 9	4	266	66.5	0.333333		
Row 10	4	268	67	0		
Row 11	4	265	66.25	0.25		
Row 12	4	266	66.5	0.333333		
Row 13	4	266	66.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.807692	12	0.150641	0.559524	0.860395	2.010183
Within Groups	10.5	39	0.269231			
Total	12.30769	51				

Table A-35: FSK Deviation vs. Minimum Preamble Pulse Width ANOVA

	Min. Preamble Width (us)					
FSK Deviation (kHz)	1	2	3	4		
80	55	54	55	55		
75	54	54	55	55		
70	55	55	54	55		
65	55	54	55	55		
60	54	55	55	54		
55	55	55	55	54		
50	55	54	55	55		
45	55	55	54	55		
40	54	54	55	55		
35	55	54	55	55		
30	55	55	55	54		
25	55	54	55	55		
20	55	54	54	55		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	219	54.75	0.25		
Row 2	4	218	54.5	0.333333		
Row 3	4	219	54.75	0.25		
Row 4	4	219	54.75	0.25		
Row 5	4	218	54.5	0.333333		
Row 6	4	219	54.75	0.25		
Row 7	4	219	54.75	0.25		
Row 8	4	219	54.75	0.25		
Row 9	4	218	54.5	0.333333		
Row 10	4	219	54.75	0.25		
Row 11	4	219	54.75	0.25		
Row 12	4	219	54.75	0.25		
Row 13	4	218	54.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.692308	12	0.057692	0.209302	0.997137	2.010183
Within Groups	10.75	39	0.275641			
Total	11.44231	51				

Table A-36: FSK Deviation vs. Maximum Sync Pulse Width ANOVA

	Max. Sync Width (us)					
FSK Deviation (kHz)	1	2	3	4		
80	56	57	56	56		
75	57	56	56	57		
70	56	56	56	57		
65	57	56	56	56		
60	57	56	57	57		
55	56	57	56	56		
50	57	56	56	56		
45	56	56	56	57		
40	57	56	57	56		
35	56	57	57	56		
30	57	56	56	57		
25	56	57	56	57		
20	57	56	56	56		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	225	56.25	0.25		
Row 2	4	226	56.5	0.333333		
Row 3	4	225	56.25	0.25		
Row 4	4	225	56.25	0.25		
Row 5	4	227	56.75	0.25		
Row 6	4	225	56.25	0.25		
Row 7	4	225	56.25	0.25		
Row 8	4	225	56.25	0.25		
Row 9	4	226	56.5	0.333333		
Row 10	4	226	56.5	0.333333		
Row 11	4	226	56.5	0.333333		
Row 12	4	226	56.5	0.333333		
Row 13	4	225	56.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.307692	12	0.108974	0.386364	0.960525	2.010183
Within Groups	11	39	0.282051			
Total	12.30769	51				

Table A-37: FSK Deviation vs. Minimum Sync Pulse Width ANOVA

	Min. Sync Width (us)					
FSK Deviation (kHz)	1	2	3	4		
80	52	51	52	52		
75	52	52	52	51		
70	51	51	52	52		
65	52	51	52	51		
60	51	52	52	51		
55	52	52	52	51		
50	51	52	51	52		
45	52	52	52	52		
40	52	52	51	51		
35	51	52	52	51		
30	51	51	52	51		
25	52	52	52	52		
20	51	52	52	51		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	207	51.75	0.25		
Row 2	4	207	51.75	0.25		
Row 3	4	206	51.5	0.333333		
Row 4	4	206	51.5	0.333333		
Row 5	4	206	51.5	0.333333		
Row 6	4	207	51.75	0.25		
Row 7	4	206	51.5	0.333333		
Row 8	4	208	52	0		
Row 9	4	206	51.5	0.333333		
Row 10	4	206	51.5	0.333333		
Row 11	4	205	51.25	0.25		
Row 12	4	208	52	0		
Row 13	4	206	51.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.307692	12	0.192308	0.75	0.695178	2.010183
Within Groups	10	39	0.25641			
Total	12.30769	51				

Table A-38: FSK Deviation vs. Maximum Data Pulse Width ANOVA

	Max. Data Width (us)			
FSK Deviation (kHz)	1	2	3	4
80	40	40	39	40
75	39	40	40	40
70	40	40	39	40
65	40	40	40	40
60	40	39	40	40
55	39	40	40	39
50	40	39	40	40
45	40	40	39	39
40	40	39	39	40
35	39	40	40	40
30	39	40	39	40
25	40	40	40	40
20	40	40	40	39
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	159	39.75	0.25
Row 2	4	159	39.75	0.25
Row 3	4	159	39.75	0.25
Row 4	4	160	40	0
Row 5	4	159	39.75	0.25
Row 6	4	158	39.5	0.333333
Row 7	4	159	39.75	0.25
Row 8	4	158	39.5	0.333333
Row 9	4	158	39.5	0.333333
Row 10	4	159	39.75	0.25
Row 11	4	158	39.5	0.333333
Row 12	4	160	40	0
Row 13	4	159	39.75	0.25

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.423077	12	0.11859	0.5	0.901927	2.010183
Within Groups	9.25	39	0.237179			
Total	10.67308	51				

Table A-39: FSK Deviation vs. Minimum Data Pulse Width ANOVA

	Min. Data Width (us)					
FSK Deviation (kHz)	1	2	3	4		
80	30	31	30	29		
75	30	30	29	30		
70	31	30	30	30		
65	30	31	29	30		
60	30	30	30	30		
55	30	29	31	29		
50	29	30	31	30		
45	30	31	30	29		
40	29	29	31	30		
35	30	30	30	29		
30	30	30	30	31		
25	30	31	29	30		
20	31	30	30	29		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	120	30	0.666667		
Row 2	4	119	29.75	0.25		
Row 3	4	121	30.25	0.25		
Row 4	4	120	30	0.666667		
Row 5	4	120	30	0		
Row 6	4	119	29.75	0.916667		
Row 7	4	120	30	0.666667		
Row 8	4	120	30	0.666667		
Row 9	4	119	29.75	0.916667		
Row 10	4	119	29.75	0.25		
Row 11	4	121	30.25	0.25		
Row 12	4	120	30	0.666667		
Row 13	4	120	30	0.666667		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.423077	12	0.11859	0.22561	0.995938	2.010183
Within Groups	20.5	39	0.525641			
Total	21.92308	51				

Table A-40: FSK Deviation vs. Maximum End Pulse Width ANOVA

	Max. End Pulse Width (us)			
FSK Deviation (kHz)	1	2	3	4
80	45	45	45	45
75	45	45	45	45
70	45	45	45	45
65	45	45	45	45
60	45	45	45	45
55	45	45	45	45
50	45	45	45	45
45	45	45	45	45
40	45	45	45	45
35	45	45	45	45
30	45	45	45	45
25	45	45	45	45
20	45	45	45	45

Table A-41: FSK Deviation vs. Minimum End Pulse Width ANOVA

	Min. End Pulse Width (us)			
FSK Deviation (kHz)	1	2	3	4
80	0	0	0	0
75	0	0	0	0
70	0	0	0	0
65	0	0	0	0
60	0	0	0	0
55	0	0	0	0
50	0	0	0	0
45	0	0	0	0
40	0	0	0	0
35	0	0	0	0
30	0	0	0	0
25	0	0	0	0
20	0	0	0	0

No variation in result data. Hence Independent.

Table A-42: FSK Deviation vs. Maximum Initialization Pulse Width ANOVA

	Max. Initialization Pulse Width (us)			
FSK Deviation (kHz)	1	2	3	4
80	20	20	20	20
75	20	20	20	20
70	20	20	20	20
65	20	20	20	20
60	20	20	20	20
55	20	20	20	20
50	20	20	20	20
45	20	20	20	20
40	20	20	20	20
35	20	20	20	20
30	20	20	20	20
25	20	20	20	20
20	20	20	20	20

Table A-43: FSK Deviation vs. Minimum Initialization Pulse Width ANOVA

	Min. Initialization Pulse Width (us)			
FSK Deviation (kHz)	1	2	3	4
80	0	0	0	0
75	0	0	0	0
70	0	0	0	0
65	0	0	0	0
60	0	0	0	0
55	0	0	0	0
50	0	0	0	0
45	0	0	0	0
40	0	0	0	0
35	0	0	0	0
30	0	0	0	0
25	0	0	0	0
20	0	0	0	0

No variation in result data. Hence Independent.

Table A-44: FSK Deviation vs. Maximum Termination Pulse Width ANOVA

	Max. Termination Pulse Width (us)			
FSK Deviation (kHz)	1	2	3	4
80	20	20	20	20
75	20	20	20	20
70	20	20	20	20
65	20	20	20	20
60	20	20	20	20
55	20	20	20	20
50	20	20	20	20
45	20	20	20	20
40	20	20	20	20
35	20	20	20	20
30	20	20	20	20
25	20	20	20	20
20	20	20	20	20

Table A-45: FSK Deviation vs. Minimum Termination Pulse Width ANOVA

	Min. Termination Pulse Width (us)			
FSK Deviation (kHz)	1	2	3	4
80	0	0	0	0
75	0	0	0	0
70	0	0	0	0
65	0	0	0	0
60	0	0	0	0
55	0	0	0	0
50	0	0	0	0
45	0	0	0	0
40	0	0	0	0
35	0	0	0	0
30	0	0	0	0
25	0	0	0	0
20	0	0	0	0

No variation in result data. Hence Independent.

Table A-46: FSK Deviation vs. Maximum Wakeup Length ANOVA

	Max. Wakeup Length (sec)			
FSK Deviation (kHz)	1	2	3	4
80	4.8	4.8	4.8	4.8
75	4.8	4.8	4.8	4.8
70	4.8	4.8	4.8	4.8
65	4.8	4.8	4.8	4.8
60	4.8	4.8	4.8	4.8
55	4.8	4.8	4.8	4.8
50	4.8	4.8	4.8	4.8
45	4.8	4.8	4.8	4.8
40	4.8	4.8	4.8	4.8
35	4.8	4.8	4.8	4.8
30	4.8	4.8	4.8	4.8
25	4.8	4.8	4.8	4.8
20	4.8	4.8	4.8	4.8

Table A-47: FSK Deviation vs. Minimum Wakeup Length ANOVA

	Min. Wakeup Length (sec)			
FSK Deviation (kHz)	1	2	3	4
80	0.8	0.8	0.8	0.8
75	0.8	0.8	0.8	0.8
70	0.8	0.8	0.8	0.8
65	0.8	0.8	0.8	0.8
60	0.8	0.8	0.8	0.8
55	0.8	0.8	0.8	0.8
50	0.8	0.8	0.8	0.8
45	0.8	0.8	0.8	0.8
40	0.8	0.8	0.8	0.8
35	0.8	0.8	0.8	0.8
30	0.8	0.8	0.8	0.8
25	0.8	0.8	0.8	0.8
20	0.8	0.8	0.8	0.8

No variation in result data. Hence Independent.

Table A-48: FSK Deviation vs. Maximum Co-Header Length ANOVA

	Max. CoHeader Length (ms)			
FSK Deviation (kHz)	1	2	3	4
80	5000	5000	5000	5000
75	5000	5000	5000	5000
70	5000	5000	5000	5000
65	5000	5000	5000	5000
60	5000	5000	5000	5000
55	5000	5000	5000	5000
50	5000	5000	5000	5000
45	5000	5000	5000	5000
40	5000	5000	5000	5000
35	5000	5000	5000	5000
30	5000	5000	5000	5000
25	5000	5000	5000	5000
20	5000	5000	5000	5000

Table A-49: FSK Deviation vs. Minimum Co-Header Length ANOVA

	Min. CoHeader Length (ms)			
FSK Deviation (kHz)	1	2	3	4
80	2.5	2.5	2.5	2.5
75	2.5	2.5	2.5	2.5
70	2.5	2.5	2.5	2.5
65	2.5	2.5	2.5	2.5
60	2.5	2.5	2.5	2.5
55	2.5	2.5	2.5	2.5
50	2.5	2.5	2.5	2.5
45	2.5	2.5	2.5	2.5
40	2.5	2.5	2.5	2.5
35	2.5	2.5	2.5	2.5
30	2.5	2.5	2.5	2.5
25	2.5	2.5	2.5	2.5
20	2.5	2.5	2.5	2.5

No variation in result data. Hence Independent.

Table A-50: FSK Deviation vs. Maximum Time between Wakeup & Co-Header ANOVA

	Max. Time between Wakeup & CoHeader (us)			
FSK Deviation (kHz)	1	2	3	4
80	800	800	800	800
75	800	800	800	800
70	800	800	800	800
65	800	800	800	800
60	800	800	800	800
55	800	800	800	800
50	800	800	800	800
45	800	800	800	800
40	800	800	800	800
35	800	800	800	800
30	800	800	800	800
25	800	800	800	800
20	800	800	800	800

Table A-51: FSK Deviation vs. Minimum Time between Wakeup & Co-Header ANOVA

	Min. Time between Wakeup & CoHeader (us)			
FSK Deviation (kHz)	1	2	3	4
80	1	1	1	1
75	1	1	1	1
70	1	1	1	1
65	1	1	1	1
60	1	1	1	1
55	1	1	1	1
50	1	1	1	1
45	1	1	1	1
40	1	1	1	1
35	1	1	1	1
30	1	1	1	1
25	1	1	1	1
20	1	1	1	1

No variation in result data. Hence Independent.

Table A-52: FSK Deviation vs. Maximum Time between Wakeup & Command ANOVA

	Max. Time between Wakeup & Command (us)			
FSK Deviation (kHz)	1	2	3	4
80	29	29	28	29
75	29	28	29	29
70	28	29	29	29
65	29	29	28	28
60	28	29	29	29
55	29	28	29	29
50	29	28	28	29
45	28	29	29	29
40	29	29	28	29
35	29	28	29	28
30	29	28	29	28
25	29	28	29	29
20	28	29	29	28

Table A-53: FSK Deviation vs. Minimum Time between Wakeup & Command ANOVA

	Min. Time between Wakeup & Command (us)			
FSK Deviation (kHz)	1	2	3	4
80	1	1	1	1
75	1	1	1	1
70	1	1	1	1
65	1	1	1	1
60	1	1	1	1
55	1	1	1	1
50	1	1	1	1
45	1	1	1	1
40	1	1	1	1
35	1	1	1	1
30	1	1	1	1
25	1	1	1	1
20	1	1	1	1

No variation in result data. Hence Independent

Table A-54: FSK Deviation vs. Maximum Tag Awake Time ANOVA

	Tag Awake Time (sec)					
FSK Deviation (kHz)	1	2	3	4		
80	29	29	28	28		
75	28	29	29	29		
70	28	28	29	28		
65	29	29	28	29		
60	28	29	29	29		
55	29	29	28	29		
50	29	28	29	28		
45	28	29	29	29		
40	29	29	28	29		
35	29	28	29	28		
30	29	28	29	29		
25	28	29	29	29		
20	29	28	29	29		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	114	28.5	0.333333		
Row 2	4	115	28.75	0.25		
Row 3	4	113	28.25	0.25		
Row 4	4	115	28.75	0.25		
Row 5	4	115	28.75	0.25		
Row 6	4	115	28.75	0.25		
Row 7	4	114	28.5	0.333333		
Row 8	4	115	28.75	0.25		
Row 9	4	115	28.75	0.25		
Row 10	4	114	28.5	0.333333		
Row 11	4	115	28.75	0.25		
Row 12	4	115	28.75	0.25		
Row 13	4	115	28.75	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.269231	12	0.105769	0.392857	0.957966	2.010183
Within Groups	10.5	39	0.269231			
Total	11.76923	51				

Table A-55: FSK Deviation vs. Minimum Number of Preambles ANOVA

	Min. No. of Preambles			
FSK Deviation (kHz)	1	2	3	4
80	8	9	8	8
75	9	8	8	9
70	8	10	8	9
65	10	8	9	8
60	8	8	9	8
55	8	9	8	9
50	9	8	8	9
45	8	8	10	10
40	10	8	8	8
35	8	10	8	9
30	9	8	8	10
25	8	9	9	8
20	9	8	9	8
SUMMARY				
Groups	*Count*	*Sum*	*Average*	*Variance*
Row 1	4	33	8.25	0.25
Row 2	4	34	8.5	0.333333
Row 3	4	35	8.75	0.916667
Row 4	4	35	8.75	0.916667
Row 5	4	33	8.25	0.25
Row 6	4	34	8.5	0.333333
Row 7	4	34	8.5	0.333333
Row 8	4	36	9	1.333333
Row 9	4	34	8.5	1
Row 10	4	35	8.75	0.916667
Row 11	4	35	8.75	0.916667
Row 12	4	34	8.5	0.333333
Row 13	4	34	8.5	0.333333

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.192308	12	0.182692	0.290816	0.987441	2.010183
Within Groups	24.5	39	0.628205			
Total	26.69231	51				

Table A-56: FSK Deviation vs. Transition Time ANOVA

	Groups of Transitions accepted			
FSK Deviation (kHz)	1	2	3	4
80	8	8	8	8
75	8	8	8	8
70	8	8	8	8
65	8	8	8	8
60	8	8	8	8
55	8	8	8	8
50	8	8	8	8
45	8	8	8	8
40	8	8	8	8
35	8	8	8	8
30	8	8	8	8
25	8	8	8	8
20	8	8	8	8

No variation in result data. Hence Independent

A.3 WAKEUP PULSE WIDTH VS.

The ANOVA tables of Wakeup Pulse Width vs.

1. End Pulse Width
2. Initialization Length
3. Termination Length
4. Wakeup Length
5. Co-Header Length
6. Time between Wakeup & Co-Header
7. Transition Time

are not included in this document as the variation in output for the mentioned factors is zero without any approximation.

Table A-57: Wakeup Pulse Width vs. Maximum Carrier ANOVA

	Max. Carrier (MHz)			
Wakeup Width (us)	1	2	3	4
15	433.94	433.94	433.94	433.94
16	433.94	433.94	433.94	433.94
17	433.94	433.94	433.94	433.94
18	433.94	433.94	433.94	433.94

Table A-58: Wakeup Pulse Width vs. Minimum Carrier ANOVA

	Min. Carrier (MHz)			
Wakeup Width (us)	1	2	3	4
15	433.88	433.88	433.88	433.88
16	433.88	433.88	433.88	433.88
17	433.88	433.88	433.88	433.88
18	433.88	433.88	433.88	433.88

No variation in result data. Hence Independent.

Table A-59: Wakeup Pulse Width vs. Maximum FSK Deviation ANOVA

	Max. FSK (kHz)					
Wakeup Width (us)	1	2	3	4		
15	80	80	80	85		
16	85	80	85	80		
17	80	85	80	80		
18	80	85	85	80		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	325	81.25	6.25		
Row 2	4	330	82.5	8.333333		
Row 3	4	325	81.25	6.25		
Row 4	4	330	82.5	8.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6.25	3	2.083333	0.285714	0.834812	3.490295
Within Groups	87.5	12	7.291667			
Total	93.75	15				

Table A-60: Wakeup Pulse Width vs. Minimum FSK Deviation ANOVA

	Min. FSK (kHz)					
Wakeup Width (us)	1	2	3	4		
15	20	20	20	20		
16	25	20	20	20		
17	20	20	20	20		
18	25	20	20	25		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	80	20	0		
Row 2	4	85	21.25	6.25		
Row 3	4	80	20	0		
Row 4	4	90	22.5	8.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	17.1875	3	5.729167	1.571429	0.24757	3.490295
Within Groups	43.75	12	3.645833			
Total	60.9375	15				

Table A-61: Wakeup Pulse Width vs. Maximum Co-Header Pulse Width ANOVA

	Max. CoHeader Pulse Width (us)					
Wakeup Width (us)	1	2	3	4		
15	56	55	56	55		
16	55	56	55	55		
17	56	56	55	55		
18	55	55	56	56		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	222	55.5	0.333333		
Row 2	4	221	55.25	0.25		
Row 3	4	222	55.5	0.333333		
Row 4	4	222	55.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.1875	3	0.0625	0.2	0.894377	3.490295
Within Groups	3.75	12	0.3125			
Total	3.9375	15				

Table A-62: Wakeup Pulse Width vs. Minimum Co-Header Pulse Width ANOVA

	Min. CoHeader Pulse Width (us)					
Wakeup Width (us)	1	2	3	4		
15	47	47	48	48		
16	48	47	48	47		
17	47	48	47	48		
18	48	47	47	47		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	190	47.5	0.333333		
Row 2	4	190	47.5	0.333333		
Row 3	4	190	47.5	0.333333		
Row 4	4	189	47.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.1875	3	0.0625	0.2	0.894377	3.490295
Within Groups	3.75	12	0.3125			
Total	3.9375	15				

Table A-63: Wakeup Pulse Width vs. Maximum Preamble Pulse Width ANOVA

	Max. Preamble Pulse Width (us)					
Wakeup Width (us)	1	2	3	4		
15	66	67	66	66		
16	67	66	66	67		
17	66	66	66	67		
18	67	66	66	66		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	265	66.25	0.25		
Row 2	4	266	66.5	0.333333		
Row 3	4	265	66.25	0.25		
Row 4	4	265	66.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.1875	3	0.0625	0.230769	0.873191	3.490295
Within Groups	3.25	12	0.270833			
Total	3.4375	15				

Table A-64: Wakeup Pulse Width vs. Minimum Preamble Pulse Width ANOVA

	Min. Preamble Pulse Width (us)					
Wakeup Width (us)	1	2	3	4		
15	55	54	55	55		
16	54	55	55	55		
17	55	54	55	54		
18	54	55	54	55		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	219	54.75	0.25		
Row 2	4	219	54.75	0.25		
Row 3	4	218	54.5	0.333333		
Row 4	4	218	54.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.25	3	0.083333	0.285714	0.834812	3.490295
Within Groups	3.5	12	0.291667			
Total	3.75	15				

Table A-65: Wakeup Pulse Width vs. Maximum Sync Pulse Width ANOVA

	Max. Sync Pulse Width (us)					
Wakeup Width (us)	1	2	3	4		
15	56	57	56	56		
16	57	56	56	57		
17	57	56	57	57		
18	56	56	56	57		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	225	56.25	0.25		
Row 2	4	226	56.5	0.333333		
Row 3	4	227	56.75	0.25		
Row 4	4	225	56.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.6875	3	0.229167	0.846154	0.494769	3.490295
Within Groups	3.25	12	0.270833			
Total	3.9375	15				

Table A-66: Wakeup Pulse Width vs. Minimum Sync Pulse Width ANOVA

	Max. Sync Pulse Width (us)					
Wakeup Width (us)	1	2	3	4		
15	51	52	51	51		
16	52	52	51	51		
17	51	51	51	51		
18	52	51	51	51		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	205	51.25	0.25		
Row 2	4	206	51.5	0.333333		
Row 3	4	204	51	0		
Row 4	4	205	51.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.5	3	0.166667	0.8	0.517404	3.490295
Within Groups	2.5	12	0.208333			
Total	3	15				

Table A-67: Wakeup Pulse Width vs. Maximum Data Pulse Width ANOVA

	Max. Data Width (us)					
Wakeup Width (us)	1	2	3	4		
15	39	39	40	40		
16	39	40	40	39		
17	40	40	40	40		
18	39	39	40	39		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	158	39.5	0.333333		
Row 2	4	158	39.5	0.333333		
Row 3	4	160	40	0		
Row 4	4	157	39.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.1875	3	0.395833	1.727273	0.214486	3.490295
Within Groups	2.75	12	0.229167			
Total	3.9375	15				

Table A-68: Wakeup Pulse Width vs. Minimum Data Pulse Width ANOVA

	Min. data Width (us)					
Wakeup Width (us)	1	2	3	4		
15	30	30	30	30		
16	30	30	30	31		
17	30	30	30	30		
18	31	30	30	30		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	120	30	0		
Row 2	4	121	30.25	0.25		
Row 3	4	120	30	0		
Row 4	4	121	30.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.25	3	0.083333	0.666667	0.588471	3.490295
Within Groups	1.5	12	0.125			
Total	1.75	15				

Table A-69: Wakeup PW vs. Maximum Time between Wakeup & Command ANOVA

	Max. Time bet Wakeup & Command					
Wakeup Width (us)	1	2	3	4		
15	28	29	28	28		
16	29	29	29	29		
17	28	29	29	28		
18	29	29	28	28		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	113	28.25	0.25		
Row 2	4	116	29	0		
Row 3	4	114	28.5	0.333333		
Row 4	4	114	28.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.1875	3	0.395833	1.727273	0.214486	3.490295
Within Groups	2.75	12	0.229167			
Total	3.9375	15				

Table A-70: Wakeup PW vs. Minimum Time between Wakeup & Command ANOVA

	Min. Time bet Wakeup & Command (us)			
Wakeup Width (us)	1	2	3	4
15	1	1	1	1
16	1	1	1	1
17	1	1	1	1
18	1	1	1	1

Table A-71: Wakeup Pulse Width vs. Tag Awake Time ANOVA

	Tag Awake Time (sec)					
Wakeup Width (us)	1	2	3	4		
15	29	28	29	29		
16	29	29	29	28		
17	29	28	29	28		
18	29	29	29	29		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	115	28.75	0.25		
Row 2	4	115	28.75	0.25		
Row 3	4	114	28.5	0.333333		
Row 4	4	116	29	0		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.5	3	0.166667	0.8	0.517404	3.490295
Within Groups	2.5	12	0.208333			
Total	3	15				

Table A-72: Wakeup Pulse Width vs. Minimum Number of Preambles ANOVA

	Min. No. of Preambles					
Wakeup Width (us)	1	2	3	4		
15	8	9	9	8		
16	9	8	8	10		
17	8	9	9	8		
18	9	8	9	8		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	34	8.5	0.333333		
Row 2	4	35	8.75	0.916667		
Row 3	4	34	8.5	0.333333		
Row 4	4	34	8.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.1875	3	0.0625	0.130435	0.940134	3.490295
Within Groups	5.75	12	0.479167			
Total	5.9375	15				

A.4 CO-HEADER WIDTH VS.

The ANOVA tables of Co-Header Pulse Width vs.

1. Carrier Frequency
2. End Pulse Width
3. Initialization Length
4. Termination Length
5. Wakeup Length
6. Co-Header Length
7. Time between Wakeup & Co-Header
8. Transition Time

are not included in this document as the variation in output for the mentioned factors is zero without any approximation.

Table A-73: Co-Header Pulse Width vs. Maximum FSK Deviation ANOVA

	Max. FSK (kHz)					
CoHeader Width (us)	1	2	3	4		
48	80	80	80	85		
49	85	80	85	80		
50	80	85	80	80		
51	80	85	85	80		
52	80	85	80	80		
53	85	80	85	80		
54	80	85	80	80		
55	80	85	85	80		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	325	81.25	6.25		
Row 2	4	330	82.5	8.333333		
Row 3	4	325	81.25	6.25		
Row 4	4	330	82.5	8.333333		
Row 5	4	325	81.25	6.25		
Row 6	4	330	82.5	8.333333		
Row 7	4	325	81.25	6.25		
Row 8	4	330	82.5	8.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	12.5	7	1.785714	0.244898	0.969012	2.422629
Within Groups	175	24	7.291667			
Total	187.5	31				

Table A-74: Co-Header Pulse Width vs. Minimum FSK Deviation ANOVA

	Min. FSK (kHz)					
CoHeader Width (us)	1	2	3	4		
48	20	20	20	20		
49	25	20	20	20		
50	20	20	20	20		
51	25	20	20	25		
52	25	20	20	20		
53	20	20	20	20		
54	25	20	20	25		
55	25	20	20	20		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	80	20	0		
Row 2	4	85	21.25	6.25		
Row 3	4	80	20	0		
Row 4	4	90	22.5	8.333333		
Row 5	4	85	21.25	6.25		
Row 6	4	80	20	0		
Row 7	4	90	22.5	8.333333		
Row 8	4	85	21.25	6.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	30.46875	7	4.352679	0.983193	0.466169	2.422629
Within Groups	106.25	24	4.427083			
Total	136.7188	31				

Table A-75: Co-Header Pulse Width vs. Maximum Wakeup Pulse Width ANOVA

	Max. Wakeup Pulse Width (us)					
CoHeader Width (us)	1	2	3	4		
48	18	19	18	19		
49	19	18	19	19		
50	19	18	18	19		
51	18	19	18	19		
52	19	18	19	18		
53	19	19	19	18		
54	18	18	18	19		
55	19	18	19	18		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	74	18.5	0.333333		
Row 2	4	75	18.75	0.25		
Row 3	4	74	18.5	0.333333		
Row 4	4	74	18.5	0.333333		
Row 5	4	74	18.5	0.333333		
Row 6	4	75	18.75	0.25		
Row 7	4	73	18.25	0.25		
Row 8	4	74	18.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.71875	7	0.102679	0.339901	0.92737	2.422629
Within Groups	7.25	24	0.302083			
Total	7.96875	31				

Table A-76: Co-Header Pulse Width vs. Minimum Wakeup Pulse Width ANOVA

	Min. Wakeup Pulse Width (us)					
CoHeader Width (us)	1	2	3	4		
48	14	15	14	14		
49	15	14	14	14		
50	14	15	14	15		
51	14	14	14	15		
52	15	14	14	14		
53	15	14	14	15		
54	14	15	15	14		
55	14	14	14	15		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	57	14.25	0.25		
Row 2	4	57	14.25	0.25		
Row 3	4	58	14.5	0.333333		
Row 4	4	57	14.25	0.25		
Row 5	4	57	14.25	0.25		
Row 6	4	58	14.5	0.333333		
Row 7	4	58	14.5	0.333333		
Row 8	4	57	14.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.46875	7	0.066964	0.238095	0.971308	2.422629
Within Groups	6.75	24	0.28125			
Total	7.21875	31				

Table A-77: Co-Header Pulse Width vs. Maximum Preamble Pulse Width ANOVA

	Max. Preamble Pulse Width (us)					
CoHeader Width (us)	1	2	3	4		
48	66	67	66	66		
49	67	66	66	67		
50	66	66	66	67		
51	67	66	66	66		
52	67	66	66	67		
53	66	67	66	66		
54	67	66	66	67		
55	66	66	66	67		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	265	66.25	0.25		
Row 2	4	266	66.5	0.333333		
Row 3	4	265	66.25	0.25		
Row 4	4	265	66.25	0.25		
Row 5	4	266	66.5	0.333333		
Row 6	4	265	66.25	0.25		
Row 7	4	266	66.5	0.333333		
Row 8	4	265	66.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.46875	7	0.066964	0.238095	0.971308	2.422629
Within Groups	6.75	24	0.28125			
Total	7.21875	31				

Table A-78: Co-Header Pulse Width vs. Minimum Preamble Pulse Width ANOVA

	Min. Preamble Pulse Width (us)					
CoHeader Width (us)	1	2	3	4		
48	54	55	55	55		
49	55	54	55	54		
50	55	54	55	55		
51	54	55	55	55		
52	55	54	55	55		
53	54	55	55	55		
54	55	54	55	54		
55	54	55	54	55		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	219	54.75	0.25		
Row 2	4	218	54.5	0.333333		
Row 3	4	219	54.75	0.25		
Row 4	4	219	54.75	0.25		
Row 5	4	219	54.75	0.25		
Row 6	4	219	54.75	0.25		
Row 7	4	218	54.5	0.333333		
Row 8	4	218	54.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.46875	7	0.066964	0.238095	0.971308	2.422629
Within Groups	6.75	24	0.28125			
Total	7.21875	31				

Table A-79: Co-Header Pulse Width vs. Maximum Sync Pulse Width ANOVA

	Max. Sync Pulse Width (us)					
CoHeader Width (us)	1	2	3	4		
48	56	57	56	56		
49	57	56	56	57		
50	57	56	57	57		
51	57	56	56	56		
52	56	57	56	56		
53	57	56	56	57		
54	57	56	57	57		
55	56	56	56	57		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	225	56.25	0.25		
Row 2	4	226	56.5	0.333333		
Row 3	4	227	56.75	0.25		
Row 4	4	225	56.25	0.25		
Row 5	4	225	56.25	0.25		
Row 6	4	226	56.5	0.333333		
Row 7	4	227	56.75	0.25		
Row 8	4	225	56.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.375	7	0.196429	0.725275	0.652174	2.422629
Within Groups	6.5	24	0.270833			
Total	7.875	31				

Table A-80: Co-Header Pulse Width vs. Minimum Sync Pulse Width ANOVA

	Min. Sync Pulse Width (us)					
CoHeader Width (us)	1	2	3	4		
48	52	51	51	51		
49	52	52	51	51		
50	51	51	51	51		
51	52	51	51	51		
52	52	52	51	51		
53	51	52	51	51		
54	52	52	51	51		
55	51	51	51	51		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	205	51.25	0.25		
Row 2	4	206	51.5	0.333333		
Row 3	4	204	51	0		
Row 4	4	205	51.25	0.25		
Row 5	4	206	51.5	0.333333		
Row 6	4	205	51.25	0.25		
Row 7	4	206	51.5	0.333333		
Row 8	4	204	51	0		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.21875	7	0.174107	0.795918	0.598205	2.422629
Within Groups	5.25	24	0.21875			
Total	6.46875	31				

Table A-81: Co-Header Pulse Width vs. Maximum Data Pulse Width ANOVA

	Max. Data Width (us)					
CoHeader Width (us)	1	2	3	4		
48	39	39	40	40		
49	39	40	40	39		
50	40	40	40	40		
51	39	39	40	39		
52	39	39	40	40		
53	39	40	40	39		
54	40	40	40	40		
55	39	39	40	39		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	158	39.5	0.333333		
Row 2	4	158	39.5	0.333333		
Row 3	4	160	40	0		
Row 4	4	157	39.25	0.25		
Row 5	4	158	39.5	0.333333		
Row 6	4	158	39.5	0.333333		
Row 7	4	160	40	0		
Row 8	4	157	39.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.375	7	0.339286	1.480519	0.221308	2.422629
Within Groups	5.5	24	0.229167			
Total	7.875	31				

Table A-82: Co-Header Pulse Width vs. Minimum Data Pulse Width ANOVA

	Min. data Width (us)					
CoHeader Width (us)	1	2	3	4		
48	30	30	30	30		
49	30	30	30	31		
50	30	30	30	30		
51	31	30	30	30		
52	30	30	30	31		
53	30	30	30	30		
54	30	30	30	31		
55	30	30	30	30		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	120	30	0		
Row 2	4	121	30.25	0.25		
Row 3	4	120	30	0		
Row 4	4	121	30.25	0.25		
Row 5	4	121	30.25	0.25		
Row 6	4	120	30	0		
Row 7	4	121	30.25	0.25		
Row 8	4	120	30	0		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.5	7	0.071429	0.571429	0.771784	2.422629
Within Groups	3	24	0.125			
Total	3.5	31				

Table A-83: Co-Header PW vs. Maximum Time between Wakeup & Command ANOVA

	Max. Time bet Wakeup & Command					
CoHeader Width (us)	1	2	3	4		
48	28	29	28	28		
49	29	29	29	29		
50	28	29	29	28		
51	29	29	28	28		
52	29	29	28	28		
53	29	29	28	28		
54	29	29	28	28		
55	29	29	28	28		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	113	28.25	0.25		
Row 2	4	116	29	0		
Row 3	4	114	28.5	0.333333		
Row 4	4	114	28.5	0.333333		
Row 5	4	114	28.5	0.333333		
Row 6	4	114	28.5	0.333333		
Row 7	4	114	28.5	0.333333		
Row 8	4	114	28.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.21875	7	0.174107	0.619048	0.734984	2.422629
Within Groups	6.75	24	0.28125			
Total	7.96875	31				

Table A-84: Co-Header PW vs. Minimum Time between Wakeup & Command ANOVA

	Min. Time bet Wakeup & Command (us)			
CoHeader Width (us)	1	2	3	4
48	1	1	1	1
49	1	1	1	1
50	1	1	1	1
51	1	1	1	1
52	1	1	1	1
53	1	1	1	1
54	1	1	1	1
55	1	1	1	1

Table A-85: Co-Header Pulse Width vs. Tag Awake Time ANOVA

	Tag Awake Time (sec)					
CoHeader Width (us)	1	2	3	4		
48	29	28	29	29		
49	29	29	29	28		
50	29	28	29	28		
51	28	29	29	29		
52	29	29	29	28		
53	29	28	29	29		
54	29	28	28	29		
55	29	28	29	28		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	115	28.75	0.25		
Row 2	4	115	28.75	0.25		
Row 3	4	114	28.5	0.333333		
Row 4	4	115	28.75	0.25		
Row 5	4	115	28.75	0.25		
Row 6	4	115	28.75	0.25		
Row 7	4	114	28.5	0.333333		
Row 8	4	114	28.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.46875	7	0.066964	0.238095	0.971308	2.422629
Within Groups	6.75	24	0.28125			
Total	7.21875	31				

Table A-86: Co-Header Pulse Width vs. Minimum Number of Prambles ANOVA

	Min. No. of Preambles					
CoHeader Width (us)	1	2	3	4		
48	8	9	9	8		
49	9	8	8	10		
50	8	9	9	8		
51	9	8	9	8		
52	8	9	9	8		
53	9	8	8	10		
54	8	9	9	8		
55	9	8	9	8		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	34	8.5	0.333333		
Row 2	4	35	8.75	0.916667		
Row 3	4	34	8.5	0.333333		
Row 4	4	34	8.5	0.333333		
Row 5	4	34	8.5	0.333333		
Row 6	4	35	8.75	0.916667		
Row 7	4	34	8.5	0.333333		
Row 8	4	34	8.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.375	7	0.053571	0.111801	0.996924	2.422629
Within Groups	11.5	24	0.479167			
Total	11.875	31				

A.5 PREAMBLE PULSE WIDTH VS.

The ANOVA tables of Preamble Pulse Width vs.

1. Carrier Frequency
2. End Pulse Width
3. Initialization Length
4. Termination Length
5. Wakeup Length
6. Co-Header Length
7. Time between Wakeup & Co-Header
8. Transition Time

are not included in this document as the variation in output for the mentioned factors is zero without any approximation.

Table A-87: Preamble Pulse Width vs. Maximum FSK Deviation ANOVA

	Max. FSK (kHz)					
Preamble Width (us)	1	2	3	4		
55	80	80	80	85		
56	85	80	85	80		
57	80	85	80	80		
58	80	85	85	80		
59	80	85	80	80		
60	85	80	85	80		
61	80	85	80	80		
62	80	85	85	80		
63	80	85	80	80		
64	85	80	85	80		
65	80	85	80	80		
66	80	85	85	80		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	325	81.25	6.25		
Row 2	4	330	82.5	8.333333		
Row 3	4	325	81.25	6.25		
Row 4	4	330	82.5	8.333333		
Row 5	4	325	81.25	6.25		
Row 6	4	330	82.5	8.333333		
Row 7	4	325	81.25	6.25		
Row 8	4	330	82.5	8.333333		
Row 9	4	325	81.25	6.25		
Row 10	4	330	82.5	8.333333		
Row 11	4	325	81.25	6.25		
Row 12	4	330	82.5	8.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	18.75	11	1.704545	0.233766	0.993282	2.066608
Within Groups	262.5	36	7.291667			
Total	281.25	47				

Table A-88: Preamble Pulse Width vs. Minimum FSK Deviation ANOVA

	Min. FSK (kHz)					
Preamble Width (us)	1	2	3	4		
55	20	20	20	20		
56	25	20	20	20		
57	20	20	20	20		
58	25	20	20	25		
59	25	20	20	20		
60	20	20	20	20		
61	25	20	20	20		
62	25	20	20	25		
63	25	20	20	20		
64	25	20	20	25		
65	20	20	20	20		
66	25	20	20	20		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	80	20	0		
Row 2	4	85	21.25	6.25		
Row 3	4	80	20	0		
Row 4	4	90	22.5	8.333333		
Row 5	4	85	21.25	6.25		
Row 6	4	80	20	0		
Row 7	4	85	21.25	6.25		
Row 8	4	90	22.5	8.333333		
Row 9	4	85	21.25	6.25		
Row 10	4	90	22.5	8.333333		
Row 11	4	80	20	0		
Row 12	4	85	21.25	6.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	43.22917	11	3.929924	0.838384	0.60438	2.066608
Within Groups	168.75	36	4.6875			
Total	211.9792	47				

Table A-89: Preamble Pulse Width vs. Maximum Wakeup Pulse Width ANOVA

	Max. Wakeup Width (us)					
Preamble Width (us)	1	2	3	4		
55	17	18	19	18		
56	18	18	17	18		
57	18	19	18	18		
58	19	17	18	18		
59	19	18	18	17		
60	17	18	18	18		
61	18	18	18	18		
62	19	17	19	19		
63	18	17	17	18		
64	19	18	18	19		
65	19	18	17	17		
66	18	18	18	18		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	72	18	0.666667		
Row 2	4	71	17.75	0.25		
Row 3	4	73	18.25	0.25		
Row 4	4	72	18	0.666667		
Row 5	4	72	18	0.666667		
Row 6	4	71	17.75	0.25		
Row 7	4	72	18	0		
Row 8	4	74	18.5	1		
Row 9	4	70	17.5	0.333333		
Row 10	4	74	18.5	0.333333		
Row 11	4	71	17.75	0.916667		
Row 12	4	72	18	0		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4	11	0.363636	0.818182	0.622659	2.066608
Within Groups	16	36	0.444444			
Total	20	47				

Table A-90: Preamble Pulse Width vs. Minimum Wakeup Pulse Width ANOVA

	Min. Wakeup Width (us)					
Preamble Width (us)	1	2	3	4		
55	15	14	15	14		
56	14	15	14	14		
57	14	14	14	14		
58	14	15	15	14		
59	14	14	14	14		
60	15	14	15	14		
61	14	14	14	14		
62	15	14	14	15		
63	14	14	14	14		
64	14	15	14	15		
65	14	14	14	14		
66	14	15	14	14		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	58	14.5	0.333333		
Row 2	4	57	14.25	0.25		
Row 3	4	56	14	0		
Row 4	4	58	14.5	0.333333		
Row 5	4	56	14	0		
Row 6	4	58	14.5	0.333333		
Row 7	4	56	14	0		
Row 8	4	58	14.5	0.333333		
Row 9	4	56	14	0		
Row 10	4	58	14.5	0.333333		
Row 11	4	56	14	0		
Row 12	4	57	14.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.5	11	0.227273	1.258741	0.286799	2.066608
Within Groups	6.5	36	0.180556			
Total	9	47				

Table A-91: Preamble Pulse Width vs. Maximum Co-Header Pulse Width ANOVA

	Max. CoHeader Width (us)					
Preamble Width (us)	1	2	3	4		
55	55	56	55	56		
56	56	55	56	55		
57	55	56	56	55		
58	56	55	55	56		
59	55	56	56	55		
60	55	56	55	56		
61	56	55	56	55		
62	55	56	55	55		
63	56	55	56	55		
64	55	56	55	56		
65	56	55	56	55		
66	55	56	55	55		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	222	55.5	0.333333		
Row 2	4	222	55.5	0.333333		
Row 3	4	222	55.5	0.333333		
Row 4	4	222	55.5	0.333333		
Row 5	4	222	55.5	0.333333		
Row 6	4	222	55.5	0.333333		
Row 7	4	222	55.5	0.333333		
Row 8	4	221	55.25	0.25		
Row 9	4	222	55.5	0.333333		
Row 10	4	222	55.5	0.333333		
Row 11	4	222	55.5	0.333333		
Row 12	4	221	55.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.416667	11	0.037879	0.118577	0.999692	2.066608
Within Groups	11.5	36	0.319444			
Total	11.91667	47				

Table A-92: Preamble Pulse Width vs. Minimum Co-Header Pulse Width ANOVA

	Min. CoHeader Width (us)					
Preamble Width (us)	1	2	3	4		
55	47	48	47	47		
56	48	47	47	48		
57	47	48	47	48		
58	48	47	47	47		
59	47	47	48	48		
60	47	47	48	47		
61	47	48	47	48		
62	48	47	47	47		
63	48	48	48	48		
64	47	48	47	48		
65	48	47	48	48		
66	48	48	48	47		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	189	47.25	0.25		
Row 2	4	190	47.5	0.333333		
Row 3	4	190	47.5	0.333333		
Row 4	4	189	47.25	0.25		
Row 5	4	190	47.5	0.333333		
Row 6	4	189	47.25	0.25		
Row 7	4	190	47.5	0.333333		
Row 8	4	189	47.25	0.25		
Row 9	4	192	48	0		
Row 10	4	190	47.5	0.333333		
Row 11	4	191	47.75	0.25		
Row 12	4	191	47.75	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.5	11	0.227273	0.861244	0.583853	2.066608
Within Groups	9.5	36	0.263889			
Total	12	47				

Table A-93: Preamble Pulse Width vs. Maximum Sync Pulse Width ANOVA

	Max. Sync Width (us)					
Preamble Width (us)	1	2	3	4		
55	56	57	56	56		
56	57	56	56	57		
57	56	56	56	57		
58	57	56	56	56		
59	57	56	57	57		
60	56	57	56	56		
61	57	56	56	56		
62	56	56	56	57		
63	57	56	57	56		
64	56	57	57	56		
65	57	56	56	57		
66	56	57	56	57		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	225	56.25	0.25		
Row 2	4	226	56.5	0.333333		
Row 3	4	225	56.25	0.25		
Row 4	4	225	56.25	0.25		
Row 5	4	227	56.75	0.25		
Row 6	4	225	56.25	0.25		
Row 7	4	225	56.25	0.25		
Row 8	4	225	56.25	0.25		
Row 9	4	226	56.5	0.333333		
Row 10	4	226	56.5	0.333333		
Row 11	4	226	56.5	0.333333		
Row 12	4	226	56.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.229167	11	0.111742	0.392461	0.950258	2.066608
Within Groups	10.25	36	0.284722			
Total	11.47917	47				

Table A-94: Preamble Pulse Width vs. Minimum Sync Pulse Width ANOVA

	Min. Sync Width (us)					
Preamble Width (us)	1	2	3	4		
55	52	51	52	52		
56	52	52	52	51		
57	51	51	52	52		
58	52	51	52	51		
59	51	52	52	51		
60	52	52	52	51		
61	51	52	51	52		
62	52	52	52	52		
63	52	52	51	51		
64	51	52	52	51		
65	51	51	52	51		
66	52	52	52	52		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	207	51.75	0.25		
Row 2	4	207	51.75	0.25		
Row 3	4	206	51.5	0.333333		
Row 4	4	206	51.5	0.333333		
Row 5	4	206	51.5	0.333333		
Row 6	4	207	51.75	0.25		
Row 7	4	206	51.5	0.333333		
Row 8	4	208	52	0		
Row 9	4	206	51.5	0.333333		
Row 10	4	206	51.5	0.333333		
Row 11	4	205	51.25	0.25		
Row 12	4	208	52	0		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.25	11	0.204545	0.818182	0.622659	2.066608
Within Groups	9	36	0.25			
Total	11.25	47				

Table A-95: Preamble Pulse Width vs. Maximum Data Pulse Width ANOVA

	Max. Data Width (us)					
Preamble Width (us)	1	2	3	4		
55	39	39	40	40		
56	39	40	40	39		
57	40	40	40	40		
58	39	39	40	39		
59	40	39	39	40		
60	40	40	40	40		
61	39	40	40	39		
62	40	39	39	40		
63	39	40	40	39		
64	40	39	39	40		
65	40	40	40	40		
66	40	40	39	40		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	158	39.5	0.333333		
Row 2	4	158	39.5	0.333333		
Row 3	4	160	40	0		
Row 4	4	157	39.25	0.25		
Row 5	4	158	39.5	0.333333		
Row 6	4	160	40	0		
Row 7	4	158	39.5	0.333333		
Row 8	4	158	39.5	0.333333		
Row 9	4	158	39.5	0.333333		
Row 10	4	158	39.5	0.333333		
Row 11	4	160	40	0		
Row 12	4	159	39.75	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.75	11	0.25	1.058824	0.419385	2.066608
Within Groups	8.5	36	0.236111			
Total	11.25	47				

Table A-96: Preamble Pulse Width vs. Minimum Data Pulse Width ANOVA

	Min. data Width (us)					
Preamble Width (us)	1	2	3	4		
55	30	30	30	30		
56	30	30	30	31		
57	30	30	30	30		
58	31	30	30	30		
59	31	30	30	30		
60	30	30	30	29		
61	31	30	30	30		
62	30	31	30	30		
63	30	30	30	30		
64	30	31	30	29		
65	31	30	30	30		
66	30	31	30	29		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	120	30	0		
Row 2	4	121	30.25	0.25		
Row 3	4	120	30	0		
Row 4	4	121	30.25	0.25		
Row 5	4	121	30.25	0.25		
Row 6	4	119	29.75	0.25		
Row 7	4	121	30.25	0.25		
Row 8	4	121	30.25	0.25		
Row 9	4	120	30	0		
Row 10	4	120	30	0.666667		
Row 11	4	121	30.25	0.25		
Row 12	4	120	30	0.666667		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.229167	11	0.111742	0.434889	0.929602	2.066608
Within Groups	9.25	36	0.256944			
Total	10.47917	47				

Table A-97: Preamble PW vs. Maximum Time between Wakeup & Command ANOVA

	Max. Time between Wakeup & Command (us)					
Preamble Width (us)	1	2	3	4		
55	29	29	28	29		
56	29	28	29	29		
57	28	29	29	29		
58	29	29	28	28		
59	28	29	29	29		
60	29	28	29	29		
61	29	28	28	29		
62	28	29	29	29		
63	29	29	28	29		
64	29	28	29	28		
65	29	28	29	28		
66	29	28	29	29		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	115	28.75	0.25		
Row 2	4	115	28.75	0.25		
Row 3	4	115	28.75	0.25		
Row 4	4	114	28.5	0.333333		
Row 5	4	115	28.75	0.25		
Row 6	4	115	28.75	0.25		
Row 7	4	114	28.5	0.333333		
Row 8	4	115	28.75	0.25		
Row 9	4	115	28.75	0.25		
Row 10	4	114	28.5	0.333333		
Row 11	4	114	28.5	0.333333		
Row 12	4	115	28.75	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.666667	11	0.060606	0.218182	0.99499	2.066608
Within Groups	10	36	0.277778			
Total	10.66667	47				

Table A-98: Preamble PW vs. Minimum Time between Wakeup & Command ANOVA

	Min. Time between Wakeup & Command (us)			
Preamble Width (us)	1	2	3	4
55	1	1	1	1
56	1	1	1	1
57	1	1	1	1
58	1	1	1	1
59	1	1	1	1
60	1	1	1	1
61	1	1	1	1
62	1	1	1	1
63	1	1	1	1
64	1	1	1	1
65	1	1	1	1
66	1	1	1	1

Table A-99: Preamble Pulse Width vs. Tag Awake Time ANOVA

	Tag Awake Time (sec)					
Preamble Width (us)	1	2	3	4		
55	29	28	29	29		
56	29	29	29	28		
57	29	28	29	28		
58	29	29	29	29		
59	28	29	29	29		
60	29	28	28	28		
61	29	29	28	28		
62	29	29	29	28		
63	29	28	29	28		
64	29	29	29	29		
65	29	29	29	29		
66	28	29	29	29		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	115	28.75	0.25		
Row 2	4	115	28.75	0.25		
Row 3	4	114	28.5	0.333333		
Row 4	4	116	29	0		
Row 5	4	115	28.75	0.25		
Row 6	4	113	28.25	0.25		
Row 7	4	114	28.5	0.333333		
Row 8	4	115	28.75	0.25		
Row 9	4	114	28.5	0.333333		
Row 10	4	116	29	0		
Row 11	4	116	29	0		
Row 12	4	115	28.75	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.416667	11	0.219697	1.054545	0.422625	2.066608
Within Groups	7.5	36	0.208333			
Total	9.916667	47				

Table A-100: Preamble Pulse Width vs. Minimum Number of Preambles ANOVA

	Min. No. of Preambles					
Preamble Width (us)	1	2	3	4		
55	8	9	9	8		
56	9	8	8	10		
57	8	9	9	8		
58	9	8	9	8		
59	8	9	8	8		
60	9	8	8	9		
61	8	10	8	9		
62	10	8	9	8		
63	9	8	8	10		
64	10	8	9	9		
65	9	8	8	10		
66	8	9	9	8		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	34	8.5	0.333333		
Row 2	4	35	8.75	0.916667		
Row 3	4	34	8.5	0.333333		
Row 4	4	34	8.5	0.333333		
Row 5	4	33	8.25	0.25		
Row 6	4	34	8.5	0.333333		
Row 7	4	35	8.75	0.916667		
Row 8	4	35	8.75	0.916667		
Row 9	4	35	8.75	0.916667		
Row 10	4	36	9	0.666667		
Row 11	4	35	8.75	0.916667		
Row 12	4	34	8.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.75	11	0.159091	0.266385	0.988477	2.066608
Within Groups	21.5	36	0.597222			
Total	23.25	47				

A.6 SYNC PULSE WIDTH VS.

The ANOVA tables of Sync Pulse Width vs.

1. Carrier Frequency
2. End Pulse Width
3. Initialization Length
4. Termination Length
5. Wakeup Length
6. Co-Header Length
7. Time between Wakeup & Co-Header
8. Transition Time

are not included in this document as the variation in output for the mentioned factors is zero without any approximation.

Table A-101: Sync Pulse Width vs. Maximum FSK Deviation ANOVA

	Max. FSK (kHz)					
Sync Width (us)	1	2	3	4		
52	80	80	80	85		
53	85	80	85	80		
54	80	85	80	80		
55	80	85	85	80		
56	80	85	80	80		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	325	81.25	6.25		
Row 2	4	330	82.5	8.333333		
Row 3	4	325	81.25	6.25		
Row 4	4	330	82.5	8.333333		
Row 5	4	325	81.25	6.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7.5	4	1.875	0.264706	0.896043	3.055568
Within Groups	106.25	15	7.083333			
Total	113.75	19				

Table A-102: Sync Pulse Width vs. Minimum FSK Deviation ANOVA

	Min. FSK (kHz)					
Sync Width (us)	1	2	3	4		
52	20	20	20	20		
53	25	20	20	20		
54	20	20	20	20		
55	25	20	20	25		
56	25	20	20	20		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	80	20	0		
Row 2	4	85	21.25	6.25		
Row 3	4	80	20	0		
Row 4	4	90	22.5	8.333333		
Row 5	4	85	21.25	6.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	17.5	4	4.375	1.05	0.414603	3.055568
Within Groups	62.5	15	4.166667			
Total	80	19				

Table A-103: Sync Pulse Width vs. Maximum Wakeup Pulse Width ANOVA

	Max. Wakeup Width (us)					
Sync Width (us)	1	2	3	4		
52	17	18	19	18		
53	18	18	17	18		
54	18	19	18	18		
55	19	17	18	18		
56	19	18	18	17		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	72	18	0.666667		
Row 2	4	71	17.75	0.25		
Row 3	4	73	18.25	0.25		
Row 4	4	72	18	0.666667		
Row 5	4	72	18	0.666667		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.5	4	0.125	0.25	0.905175	3.055568
Within Groups	7.5	15	0.5			
Total	8	19				

Table A-104: Sync Pulse Width vs. Minimum Wakeup Pulse Width ANOVA

	Min. Wakeup Width (us)					
Sync Width (us)	1	2	3	4		
52	15	14	15	14		
53	14	15	14	14		
54	14	14	14	14		
55	14	15	15	14		
56	14	14	14	14		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	58	14.5	0.333333		
Row 2	4	57	14.25	0.25		
Row 3	4	56	14	0		
Row 4	4	58	14.5	0.333333		
Row 5	4	56	14	0		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1	4	0.25	1.363636	0.29301	3.055568
Within Groups	2.75	15	0.183333			
Total	3.75	19				

Table A-105: Sync Pulse Width vs. Maximum Co-Header Pulse Width ANOVA

	Max. CoHeader Width (us)					
Sync Width (us)	1	2	3	4		
52	55	56	55	56		
53	56	55	56	55		
54	55	56	56	55		
55	56	55	55	56		
56	55	56	56	55		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	222	55.5	0.333333		
Row 2	4	222	55.5	0.333333		
Row 3	4	222	55.5	0.333333		
Row 4	4	222	55.5	0.333333		
Row 5	4	222	55.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0	4	0	0	1	3.055568
Within Groups	5	15	0.333333			
Total	5	19				

Table A-106: Sync Pulse Width vs. Minimum Co-Header Pulse Width ANOVA

	Min. Wakeup Width (us)					
Sync Width (us)	1	2	3	4		
52	47	48	47	47		
53	48	47	47	48		
54	47	48	47	48		
55	48	47	47	47		
56	47	47	48	48		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	189	47.25	0.25		
Row 2	4	190	47.5	0.333333		
Row 3	4	190	47.5	0.333333		
Row 4	4	189	47.25	0.25		
Row 5	4	190	47.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.25	0.905175	3.055568
Within Groups	4.5	15	0.3			
Total	4.8	19				

Table A-107: Sync Pulse Width vs. Maximum Preamble Pulse Width ANOVA

	Max. Preamble Pulse Width (us)					
Sync Width (us)	1	2	3	4		
52	66	67	66	66		
53	67	66	66	67		
54	66	66	66	67		
55	67	66	66	66		
56	67	66	66	67		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	265	66.25	0.25		
Row 2	4	266	66.5	0.333333		
Row 3	4	265	66.25	0.25		
Row 4	4	265	66.25	0.25		
Row 5	4	266	66.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.264706	0.896043	3.055568
Within Groups	4.25	15	0.283333			
Total	4.55	19				

Table A-108: Sync Pulse Width vs. Minimum Preamble Pulse Width ANOVA

	Min. Preamble Pulse Width (us)					
Sync Width (us)	1	2	3	4		
52	55	54	55	55		
53	54	55	55	55		
54	55	54	55	54		
55	54	55	54	55		
56	54	55	55	55		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	219	54.75	0.25		
Row 2	4	219	54.75	0.25		
Row 3	4	218	54.5	0.333333		
Row 4	4	218	54.5	0.333333		
Row 5	4	219	54.75	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.264706	0.896043	3.055568
Within Groups	4.25	15	0.283333			
Total	4.55	19				

Table A-109: Sync Pulse Width vs. Maximum Data Pulse Width ANOVA

	Max. Data Width (us)					
Sync Width (us)	1	2	3	4		
52	39	39	40	40		
53	39	40	40	39		
54	40	40	40	40		
55	39	39	40	39		
56	40	39	39	40		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	158	39.5	0.333333		
Row 2	4	158	39.5	0.333333		
Row 3	4	160	40	0		
Row 4	4	157	39.25	0.25		
Row 5	4	158	39.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.2	4	0.3	1.2	0.351289	3.055568
Within Groups	3.75	15	0.25			
Total	4.95	19				

Table A-110: Sync Pulse Width vs. Minimum Data Pulse Width ANOVA

	Min. data Width (us)					
Sync Width (us)	1	2	3	4		
52	30	30	30	30		
53	30	30	30	31		
54	30	30	30	30		
55	31	30	30	30		
56	31	30	30	30		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	120	30	0		
Row 2	4	121	30.25	0.25		
Row 3	4	120	30	0		
Row 4	4	121	30.25	0.25		
Row 5	4	121	30.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.5	0.736239	3.055568
Within Groups	2.25	15	0.15			
Total	2.55	19				

Table A-111: Sync PW vs. Maximum Time between Wakeup & Command ANOVA

	Max. Time between Wakeup & Command (us)					
Sync Width (us)	1	2	3	4		
52	29	29	28	29		
53	29	28	29	29		
54	28	29	29	29		
55	29	29	28	28		
56	28	29	29	29		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	115	28.75	0.25		
Row 2	4	115	28.75	0.25		
Row 3	4	115	28.75	0.25		
Row 4	4	114	28.5	0.333333		
Row 5	4	115	28.75	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.2	4	0.05	0.1875	0.941252	3.055568
Within Groups	4	15	0.266667			
Total	4.2	19				

Table A-112: Sync PW vs. Minimum Time between Wakeup & Command ANOVA

	Min. Time between Wakeup & Command (us)			
Sync Width (us)	1	2	3	4
52	1	1	1	1
53	1	1	1	1
54	1	1	1	1
55	1	1	1	1
56	1	1	1	1

Table A-113: Sync Pulse Width vs. Tag Awake Time ANOVA

	Tag Awake Time (sec)					
Sync Width (us)	1	2	3	4		
52	29	28	29	29		
53	29	29	29	28		
54	29	28	29	28		
55	29	29	29	29		
56	28	29	29	29		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	115	28.75	0.25		
Row 2	4	115	28.75	0.25		
Row 3	4	114	28.5	0.333333		
Row 4	4	116	29	0		
Row 5	4	115	28.75	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.5	4	0.125	0.576923	0.683787	3.055568
Within Groups	3.25	15	0.216667			
Total	3.75	19				

Table A-114: Sync Pulse Width vs. Minimum Number of Preambles ANOVA

	Min. No. of Preambles					
Sync Width (us)	1	2	3	4		
52	8	9	9	8		
53	9	8	8	10		
54	8	9	9	8		
55	9	8	9	8		
56	8	9	8	8		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	34	8.5	0.333333		
Row 2	4	35	8.75	0.916667		
Row 3	4	34	8.5	0.333333		
Row 4	4	34	8.5	0.333333		
Row 5	4	33	8.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.5	4	0.125	0.288462	0.880897	3.055568
Within Groups	6.5	15	0.433333			
Total	7	19				

A.7 DATA PULSE WIDTH VS.

The ANOVA tables of Data Pulse Width vs.

1. Carrier Frequency
2. End Pulse Width
3. Initialization Length
4. Termination Length
5. Wakeup Length
6. Co-Header Length
7. Time between Wakeup & Co-Header
8. Transition Time

are not included in this document as the variation in output for the mentioned factors is zero without any approximation.

Table A-115: Data Pulse Width vs. Maximum FSK Deviation ANOVA

	Max. FSK (kHz)			
Data Width (us)	1	2	3	4
31	80	80	80	85
32	85	80	85	80
33	80	85	80	80
34	80	85	85	80
35	80	85	80	80
36	85	80	85	80
37	80	85	80	80
38	80	85	85	80
39	80	85	80	80
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	325	81.25	6.25
Row 2	4	330	82.5	8.333333
Row 3	4	325	81.25	6.25
Row 4	4	330	82.5	8.333333
Row 5	4	325	81.25	6.25
Row 6	4	330	82.5	8.333333
Row 7	4	325	81.25	6.25
Row 8	4	330	82.5	8.333333
Row 9	4	325	81.25	6.25

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	13.88889	8	1.736111	0.241935	0.978791	2.305313
Within Groups	193.75	27	7.175926			
Total	207.6389	35				

Table A-116: Data Pulse Width vs. Minimum FSK Deviation ANOVA

	Min. FSK (kHz)					
Data Width (us)	1	2	3	4		
31	20	20	20	20		
32	25	20	20	20		
33	20	20	20	20		
34	25	20	20	25		
35	25	20	20	20		
36	20	20	20	20		
37	25	20	20	20		
38	25	20	20	25		
39	25	20	20	20		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	80	20	0		
Row 2	4	85	21.25	6.25		
Row 3	4	80	20	0		
Row 4	4	90	22.5	8.333333		
Row 5	4	85	21.25	6.25		
Row 6	4	80	20	0		
Row 7	4	85	21.25	6.25		
Row 8	4	90	22.5	8.333333		
Row 9	4	85	21.25	6.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	30.55556	8	3.819444	0.825	0.588032	2.305313
Within Groups	125	27	4.62963			
Total	155.5556	35				

Table A-117: Data Pulse Width vs. Maximum Wakeup Pulse Width ANOVA

	Max. Wakeup Width (us)			
Data Width (us)	1	2	3	4
31	17	18	19	18
32	18	18	17	18
33	18	19	18	18
34	19	17	18	18
35	19	18	18	17
36	17	18	18	18
37	18	18	18	18
38	19	17	19	19
39	18	17	17	18
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	72	18	0.666667
Row 2	4	71	17.75	0.25
Row 3	4	73	18.25	0.25
Row 4	4	72	18	0.666667
Row 5	4	72	18	0.666667
Row 6	4	71	17.75	0.25
Row 7	4	72	18	0
Row 8	4	74	18.5	1
Row 9	4	70	17.5	0.333333

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.722222	8	0.340278	0.75	0.647984	2.305313
Within Groups	12.25	27	0.453704			
Total	14.97222	35				

Table A-118: Data Pulse Width vs. Minimum Wakeup Pulse Width ANOVA

	Min. Wakeup Width (us)					
Data Width (us)	1	2	3	4		
31	15	14	15	14		
32	14	15	14	14		
33	14	14	14	14		
34	14	15	15	14		
35	14	14	14	14		
36	15	14	15	14		
37	14	14	14	14		
38	15	14	14	15		
39	14	14	14	14		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	58	14.5	0.333333		
Row 2	4	57	14.25	0.25		
Row 3	4	56	14	0		
Row 4	4	58	14.5	0.333333		
Row 5	4	56	14	0		
Row 6	4	58	14.5	0.333333		
Row 7	4	56	14	0		
Row 8	4	58	14.5	0.333333		
Row 9	4	56	14	0		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2	8	0.25	1.421053	0.232827	2.305313
Within Groups	4.75	27	0.175926			
Total	6.75	35				

Table A-119: Data Pulse Width vs. Maximum Co-Header Pulse Width ANOVA

	Max. CoHeader Width (us)			
Data Width (us)	1	2	3	4
31	55	56	55	56
32	56	55	56	55
33	55	56	56	55
34	56	55	55	56
35	55	56	56	55
36	55	56	55	56
37	56	55	56	55
38	55	56	55	55
39	56	55	56	55
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	222	55.5	0.333333
Row 2	4	222	55.5	0.333333
Row 3	4	222	55.5	0.333333
Row 4	4	222	55.5	0.333333
Row 5	4	222	55.5	0.333333
Row 6	4	222	55.5	0.333333
Row 7	4	222	55.5	0.333333
Row 8	4	221	55.25	0.25
Row 9	4	222	55.5	0.333333

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.222222	8	0.027778	0.085714	0.999388	2.305313
Within Groups	8.75	27	0.324074			
Total	8.972222	35				

Table A-120: Data Pulse Width vs. Minimum Co-Header Pulse Width ANOVA

	Min. CoHeader Width (us)			
Data Width (us)	1	2	3	4
31	47	48	47	47
32	48	47	47	48
33	47	48	47	48
34	48	47	47	47
35	47	47	48	48
36	47	47	48	47
37	47	48	47	48
38	48	47	47	47
39	48	48	48	48
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	189	47.25	0.25
Row 2	4	190	47.5	0.333333
Row 3	4	190	47.5	0.333333
Row 4	4	189	47.25	0.25
Row 5	4	190	47.5	0.333333
Row 6	4	189	47.25	0.25
Row 7	4	190	47.5	0.333333
Row 8	4	189	47.25	0.25
Row 9	4	192	48	0

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.888889	8	0.236111	0.910714	0.522403	2.305313
Within Groups	7	27	0.259259			
Total	8.888889	35				

Table A-121: Data Pulse Width vs. Maximum Preamble Pulse Width ANOVA

	Max. Preamble Pulse Width (us)			
Data Width (us)	1	2	3	4
31	66	67	66	66
32	67	66	66	67
33	66	66	66	67
34	67	66	66	66
35	67	66	66	67
36	67	66	66	67
37	66	66	66	67
38	66	67	66	66
39	67	66	66	67
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	265	66.25	0.25
Row 2	4	266	66.5	0.333333
Row 3	4	265	66.25	0.25
Row 4	4	265	66.25	0.25
Row 5	4	266	66.5	0.333333
Row 6	4	266	66.5	0.333333
Row 7	4	265	66.25	0.25
Row 8	4	265	66.25	0.25
Row 9	4	266	66.5	0.333333

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.555556	8	0.069444	0.241935	0.978791	2.305313
Within Groups	7.75	27	0.287037			
Total	8.305556	35				

Table A-122: Data Pulse Width vs. Minimum Preamble Pulse Width ANOVA

	Min. Preamble Pulse Width (us)			
Data Width (us)	1	2	3	4
31	55	54	55	55
32	54	55	55	55
33	55	54	55	54
34	54	55	54	55
35	54	55	55	55
36	54	55	54	55
37	55	54	55	55
38	54	55	55	55
39	55	54	55	54
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	219	54.75	0.25
Row 2	4	219	54.75	0.25
Row 3	4	218	54.5	0.333333
Row 4	4	218	54.5	0.333333
Row 5	4	219	54.75	0.25
Row 6	4	218	54.5	0.333333
Row 7	4	219	54.75	0.25
Row 8	4	219	54.75	0.25
Row 9	4	218	54.5	0.333333

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.555556	8	0.069444	0.241935	0.978791	2.305313
Within Groups	7.75	27	0.287037			
Total	8.305556	35				

Table A-123: Data Pulse Width vs. Maximum Sync Pulse Width ANOVA

	Max. Sync Width (us)			
Data Width (us)	1	2	3	4
31	56	57	56	56
32	57	56	56	57
33	56	56	56	57
34	57	56	56	56
35	57	56	57	57
36	56	57	56	56
37	57	56	56	56
38	56	56	56	57
39	57	56	57	56
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	225	56.25	0.25
Row 2	4	226	56.5	0.333333
Row 3	4	225	56.25	0.25
Row 4	4	225	56.25	0.25
Row 5	4	227	56.75	0.25
Row 6	4	225	56.25	0.25
Row 7	4	225	56.25	0.25
Row 8	4	225	56.25	0.25
Row 9	4	226	56.5	0.333333

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.055556	8	0.131944	0.491379	0.851513	2.305313
Within Groups	7.25	27	0.268519			
Total	8.305556	35				

Table A-124: Data Pulse Width vs. Minimum Sync Pulse Width ANOVA

	Min. Sync Width (us)			
Data Width (us)	1	2	3	4
31	52	51	52	52
32	52	52	52	51
33	51	51	52	52
34	52	51	52	51
35	51	52	52	51
36	52	52	52	51
37	51	52	51	52
38	52	52	52	52
39	52	52	51	51
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	207	51.75	0.25
Row 2	4	207	51.75	0.25
Row 3	4	206	51.5	0.333333
Row 4	4	206	51.5	0.333333
Row 5	4	206	51.5	0.333333
Row 6	4	207	51.75	0.25
Row 7	4	206	51.5	0.333333
Row 8	4	208	52	0
Row 9	4	206	51.5	0.333333

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.055556	8	0.131944	0.491379	0.851513	2.305313
Within Groups	7.25	27	0.268519			
Total	8.305556	35				

Table A-125: Data PW vs. Maximum Time between Wakeup & Command ANOVA

	Max. Time between Wakeup & Command (us)			
Data Width (us)	1	2	3	4
31	29	29	28	29
32	29	28	29	29
33	28	29	29	29
34	29	29	28	28
35	28	29	29	29
36	29	28	29	29
37	28	29	29	29
38	29	29	28	28
39	28	29	29	29
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	115	28.75	0.25
Row 2	4	115	28.75	0.25
Row 3	4	115	28.75	0.25
Row 4	4	114	28.5	0.333333
Row 5	4	115	28.75	0.25
Row 6	4	115	28.75	0.25
Row 7	4	115	28.75	0.25
Row 8	4	114	28.5	0.333333
Row 9	4	115	28.75	0.25

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.388889	8	0.048611	0.181034	0.991621	2.305313
Within Groups	7.25	27	0.268519			
Total	7.638889	35				

Table A-126: Data PW vs. Minimum Time between Wakeup & Command ANOVA

	Min. Time between Wakeup & Command (us)			
Data Width (us)	1	2	3	4
31	1	1	1	1
32	1	1	1	1
33	1	1	1	1
34	1	1	1	1
35	1	1	1	1
36	1	1	1	1
37	1	1	1	1
38	1	1	1	1
39	1	1	1	1

Table A-127: Data Pulse Width vs. Tag Awake Time ANOVA

	Tag Awake Time (sec)			
Data Width (us)	1	2	3	4
31	28	29	29	29
32	29	29	29	28
33	29	28	29	28
34	29	29	29	29
35	28	29	29	29
36	29	28	28	28
37	29	29	28	28
38	29	29	29	28
39	29	28	29	28
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	115	28.75	0.25
Row 2	4	115	28.75	0.25
Row 3	4	114	28.5	0.333333
Row 4	4	116	29	0
Row 5	4	115	28.75	0.25
Row 6	4	113	28.25	0.25
Row 7	4	114	28.5	0.333333
Row 8	4	115	28.75	0.25
Row 9	4	114	28.5	0.333333

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.555556	8	0.194444	0.777778	0.62558	2.305313
Within Groups	6.75	27	0.25			
Total	8.305556	35				

Table A-128: Data Pulse Width vs. Minimum Number of Preambles ANOVA

	Min. No. of Preambles			
Data Width (us)	1	2	3	4
31	8	9	9	8
32	9	8	8	10
33	8	9	9	8
34	9	8	9	8
35	8	9	8	8
36	9	8	8	9
37	8	10	8	9
38	10	8	9	8
39	9	8	8	10
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	34	8.5	0.333333
Row 2	4	35	8.75	0.916667
Row 3	4	34	8.5	0.333333
Row 4	4	34	8.5	0.333333
Row 5	4	33	8.25	0.25
Row 6	4	34	8.5	0.333333
Row 7	4	35	8.75	0.916667
Row 8	4	35	8.75	0.916667
Row 9	4	35	8.75	0.916667

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1	8	0.125	0.214286	0.985514	2.305313
Within Groups	15.75	27	0.583333			
Total	16.75	35				

A.8 END PULSE LENGTH VS.

The ANOVA tables of End Pulse Length vs.

1. Carrier Frequency
2. End Pulse Width
3. Initialization Length
4. Termination Length
5. Wakeup Length
6. Co-Header Length
7. Transition Time

are not included in this document as the variation in output for the mentioned factors is zero without any approximation.

Table A-129: End Pulse Width vs. Maximum FSK Deviation ANOVA

	Max. FSK (kHz)					
End Pulse Width (us)	1	2	3	4		
32	80	80	80	85		
33	85	80	85	80		
34	80	85	80	80		
35	80	85	85	80		
36	80	85	80	80		
37	85	80	85	80		
38	80	85	80	80		
39	80	85	85	80		
40	80	85	80	80		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	325	81.25	6.25		
Row 2	4	330	82.5	8.333333		
Row 3	4	325	81.25	6.25		
Row 4	4	330	82.5	8.333333		
Row 5	4	325	81.25	6.25		
Row 6	4	330	82.5	8.333333		
Row 7	4	325	81.25	6.25		
Row 8	4	330	82.5	8.333333		
Row 9	4	325	81.25	6.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	13.88889	8	1.736111	0.241935	0.978791	2.305313
Within Groups	193.75	27	7.175926			
Total	207.6389	35				

Table A-130: End Pulse Width vs. Minimum FSK Deviation ANOVA

	Min. FSK (kHz)					
End Pulse Width (us)	1	2	3	4		
32	20	20	20	20		
33	25	20	20	20		
34	20	20	20	20		
35	25	20	20	25		
36	25	20	20	20		
37	20	20	20	20		
38	25	20	20	20		
39	25	20	20	25		
40	25	20	20	20		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	80	20	0		
Row 2	4	85	21.25	6.25		
Row 3	4	80	20	0		
Row 4	4	90	22.5	8.333333		
Row 5	4	85	21.25	6.25		
Row 6	4	80	20	0		
Row 7	4	85	21.25	6.25		
Row 8	4	90	22.5	8.333333		
Row 9	4	85	21.25	6.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	30.55556	8	3.819444	0.825	0.588032	2.305313
Within Groups	125	27	4.62963			
Total	155.5556	35				

Table A-131: End Pulse Width vs. Maximum Wakeup Pulse Width ANOVA

	Max. Wakeup Width (us)					
End Pulse Width (us)	1	2	3	4		
32	17	18	19	18		
33	18	18	17	18		
34	18	19	18	18		
35	19	17	18	18		
36	19	18	18	17		
37	17	18	18	18		
38	18	18	18	18		
39	19	17	19	19		
40	18	17	17	18		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	72	18	0.666667		
Row 2	4	71	17.75	0.25		
Row 3	4	73	18.25	0.25		
Row 4	4	72	18	0.666667		
Row 5	4	72	18	0.666667		
Row 6	4	71	17.75	0.25		
Row 7	4	72	18	0		
Row 8	4	74	18.5	1		
Row 9	4	70	17.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.722222	8	0.340278	0.75	0.647984	2.305313
Within Groups	12.25	27	0.453704			
Total	14.97222	35				

Table A-132: End Pulse Width vs. Minimum Wakeup Pulse Width ANOVA

	Min. Wakeup Width (us)					
End Pulse Width (us)	1	2	3	4		
32	15	14	15	14		
33	14	15	14	14		
34	14	14	14	14		
35	14	15	15	14		
36	14	14	14	14		
37	15	14	15	14		
38	14	14	14	14		
39	15	14	14	15		
40	14	14	14	14		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	58	14.5	0.333333		
Row 2	4	57	14.25	0.25		
Row 3	4	56	14	0		
Row 4	4	58	14.5	0.333333		
Row 5	4	56	14	0		
Row 6	4	58	14.5	0.333333		
Row 7	4	56	14	0		
Row 8	4	58	14.5	0.333333		
Row 9	4	56	14	0		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2	8	0.25	1.421053	0.232827	2.305313
Within Groups	4.75	27	0.175926			
Total	6.75	35				

Table A-133: End Pulse Width vs. Maximum Co-Header Pulse Width ANOVA

	Max. CoHeader Width (us)					
End Pulse Width (us)	1	2	3	4		
32	55	56	55	56		
33	56	55	56	55		
34	55	56	56	55		
35	56	55	55	56		
36	55	56	56	55		
37	55	56	55	56		
38	56	55	56	55		
39	55	56	55	55		
40	56	55	56	55		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	222	55.5	0.333333		
Row 2	4	222	55.5	0.333333		
Row 3	4	222	55.5	0.333333		
Row 4	4	222	55.5	0.333333		
Row 5	4	222	55.5	0.333333		
Row 6	4	222	55.5	0.333333		
Row 7	4	222	55.5	0.333333		
Row 8	4	221	55.25	0.25		
Row 9	4	222	55.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.222222	8	0.027778	0.085714	0.999388	2.305313
Within Groups	8.75	27	0.324074			
Total	8.972222	35				

Table A-134: End Pulse Width vs. Minimum Co-Header Pulse Width ANOVA

	Min. CoHeader Width (us)					
End Pulse Width (us)	1	2	3	4		
32	47	48	47	47		
33	48	47	47	48		
34	47	48	47	48		
35	48	47	47	47		
36	47	47	48	48		
37	47	47	48	47		
38	47	48	47	48		
39	48	47	47	47		
40	48	48	48	48		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	189	47.25	0.25		
Row 2	4	190	47.5	0.333333		
Row 3	4	190	47.5	0.333333		
Row 4	4	189	47.25	0.25		
Row 5	4	190	47.5	0.333333		
Row 6	4	189	47.25	0.25		
Row 7	4	190	47.5	0.333333		
Row 8	4	189	47.25	0.25		
Row 9	4	192	48	0		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.888889	8	0.236111	0.910714	0.522403	2.305313
Within Groups	7	27	0.259259			
Total	8.888889	35				

Table A-135: End Pulse Width vs. Maximum Preamble Pulse Width ANOVA

	Max. Preamble Pulse Width (us)					
End Pulse Width (us)	1	2	3	4		
32	66	67	66	66		
33	67	66	66	67		
34	66	66	66	67		
35	67	66	66	66		
36	67	66	66	67		
37	67	66	66	67		
38	66	66	66	67		
39	66	67	66	66		
40	67	66	66	67		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	265	66.25	0.25		
Row 2	4	266	66.5	0.333333		
Row 3	4	265	66.25	0.25		
Row 4	4	265	66.25	0.25		
Row 5	4	266	66.5	0.333333		
Row 6	4	266	66.5	0.333333		
Row 7	4	265	66.25	0.25		
Row 8	4	265	66.25	0.25		
Row 9	4	266	66.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.555556	8	0.069444	0.241935	0.978791	2.305313
Within Groups	7.75	27	0.287037			
Total	8.305556	35				

Table A-136: End Pulse Width vs. Minimum Preamble Pulse Width ANOVA

	Min. Preamble Pulse Width (us)			
End Pulse Width (us)	1	2	3	4
32	55	54	55	55
33	54	55	55	55
34	55	54	55	54
35	54	55	54	55
36	54	55	55	55
37	54	55	54	55
38	55	54	55	55
39	54	55	55	55
40	55	54	55	54
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	219	54.75	0.25
Row 2	4	219	54.75	0.25
Row 3	4	218	54.5	0.333333
Row 4	4	218	54.5	0.333333
Row 5	4	219	54.75	0.25
Row 6	4	218	54.5	0.333333
Row 7	4	219	54.75	0.25
Row 8	4	219	54.75	0.25
Row 9	4	218	54.5	0.333333

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.555556	8	0.069444	0.241935	0.978791	2.305313
Within Groups	7.75	27	0.287037			
Total	8.305556	35				

Table A-137: End Pulse Width vs. Maximum Sync Pulse Width ANOVA

	Max. Sync Width (us)					
End Pulse Width (us)	1	2	3	4		
32	56	57	56	56		
33	57	56	56	57		
34	56	56	56	57		
35	57	56	56	56		
36	57	56	57	57		
37	56	57	56	56		
38	57	56	56	56		
39	56	56	56	57		
40	57	56	57	56		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	225	56.25	0.25		
Row 2	4	226	56.5	0.333333		
Row 3	4	225	56.25	0.25		
Row 4	4	225	56.25	0.25		
Row 5	4	227	56.75	0.25		
Row 6	4	225	56.25	0.25		
Row 7	4	225	56.25	0.25		
Row 8	4	225	56.25	0.25		
Row 9	4	226	56.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.055556	8	0.131944	0.491379	0.851513	2.305313
Within Groups	7.25	27	0.268519			
Total	8.305556	35				

Table A-138: End Pulse Width vs. Minimum Sync Pulse Width ANOVA

	Min. Sync Width (us)					
End Pulse Width (us)	1	2	3	4		
32	52	51	52	52		
33	52	52	52	51		
34	51	51	52	52		
35	52	51	52	51		
36	51	52	52	51		
37	52	52	52	51		
38	51	52	51	52		
39	52	52	52	52		
40	52	52	51	51		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	207	51.75	0.25		
Row 2	4	207	51.75	0.25		
Row 3	4	206	51.5	0.333333		
Row 4	4	206	51.5	0.333333		
Row 5	4	206	51.5	0.333333		
Row 6	4	207	51.75	0.25		
Row 7	4	206	51.5	0.333333		
Row 8	4	208	52	0		
Row 9	4	206	51.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.055556	8	0.131944	0.491379	0.851513	2.305313
Within Groups	7.25	27	0.268519			
Total	8.305556	35				

Table A-139: End Pulse Width vs. Maximum Data Pulse Width ANOVA

	Max. Data Width (us)					
End Pulse Width (us)	1	2	3	4		
32	39	39	40	40		
33	39	40	40	39		
34	40	40	40	40		
35	39	39	40	39		
36	40	39	39	40		
37	40	40	40	40		
38	39	40	40	39		
39	40	39	39	40		
40	39	40	40	39		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	158	39.5	0.333333		
Row 2	4	158	39.5	0.333333		
Row 3	4	160	40	0		
Row 4	4	157	39.25	0.25		
Row 5	4	158	39.5	0.333333		
Row 6	4	160	40	0		
Row 7	4	158	39.5	0.333333		
Row 8	4	158	39.5	0.333333		
Row 9	4	158	39.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2	8	0.25	1	0.458584	2.305313
Within Groups	6.75	27	0.25			
Total	8.75	35				

Table A-140: End Pulse Width vs. Minimum Data Pulse Width ANOVA

	Min. data Width (us)			
End Pulse Width (us)	1	2	3	4
32	30	30	30	30
33	30	30	30	31
34	30	30	30	30
35	31	30	30	30
36	31	30	30	30
37	30	30	30	29
38	31	30	30	30
39	30	31	30	30
40	30	30	30	30
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	120	30	0
Row 2	4	121	30.25	0.25
Row 3	4	120	30	0
Row 4	4	121	30.25	0.25
Row 5	4	121	30.25	0.25
Row 6	4	119	29.75	0.25
Row 7	4	121	30.25	0.25
Row 8	4	121	30.25	0.25
Row 9	4	120	30	0

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.055556	8	0.131944	0.791667	0.614457	2.305313
Within Groups	4.5	27	0.166667			
Total	5.555556	35				

Table A-141: End PW vs. Maximum Time between Wakeup & Command ANOVA

	Max. Time between Wakeup & Command (us)					
End Pulse Width (us)	1	2	3	4		
32	29	29	28	29		
33	29	28	29	29		
34	28	29	29	29		
35	29	29	28	28		
36	28	29	29	29		
37	29	28	29	29		
38	29	28	28	29		
39	28	29	29	29		
40	29	29	28	29		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	115	28.75	0.25		
Row 2	4	115	28.75	0.25		
Row 3	4	115	28.75	0.25		
Row 4	4	114	28.5	0.333333		
Row 5	4	115	28.75	0.25		
Row 6	4	115	28.75	0.25		
Row 7	4	114	28.5	0.333333		
Row 8	4	115	28.75	0.25		
Row 9	4	115	28.75	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.388889	8	0.048611	0.181034	0.991621	2.305313
Within Groups	7.25	27	0.268519			
Total	7.638889	35				

Table A-142: End PW vs. Minimum Time between Wakeup & Command ANOVA

	Min. Time between Wakeup & Command (us)			
End Pulse Width (us)	1	2	3	4
32	1	1	1	1
33	1	1	1	1
34	1	1	1	1
35	1	1	1	1
36	1	1	1	1
37	1	1	1	1
38	1	1	1	1
39	1	1	1	1
40	1	1	1	1

Table A-143: End Pulse Width vs. Tag Awake Time ANOVA

	Tag Awake Time (sec)					
End Pulse Width (us)	1	2	3	4		
32	29	28	29	29		
33	29	29	29	28		
34	29	28	29	28		
35	29	29	29	29		
36	28	29	29	29		
37	29	28	28	28		
38	29	29	28	28		
39	29	29	29	28		
40	29	28	29	28		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	115	28.75	0.25		
Row 2	4	115	28.75	0.25		
Row 3	4	114	28.5	0.333333		
Row 4	4	116	29	0		
Row 5	4	115	28.75	0.25		
Row 6	4	113	28.25	0.25		
Row 7	4	114	28.5	0.333333		
Row 8	4	115	28.75	0.25		
Row 9	4	114	28.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.555556	8	0.194444	0.777778	0.62558	2.305313
Within Groups	6.75	27	0.25			
Total	8.305556	35				

Table A-144: End Pulse Width vs. Minimum Number of Preambles ANOVA

	Min. No. of Preambles					
End Pulse Width (us)	1	2	3	4		
32	8	9	9	8		
33	9	8	8	10		
34	8	9	9	8		
35	9	8	9	8		
36	8	9	8	8		
37	9	8	8	9		
38	8	10	8	9		
39	10	8	9	8		
40	9	8	8	10		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	34	8.5	0.333333		
Row 2	4	35	8.75	0.916667		
Row 3	4	34	8.5	0.333333		
Row 4	4	34	8.5	0.333333		
Row 5	4	33	8.25	0.25		
Row 6	4	34	8.5	0.333333		
Row 7	4	35	8.75	0.916667		
Row 8	4	35	8.75	0.916667		
Row 9	4	35	8.75	0.916667		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1	8	0.125	0.214286	0.985514	2.305313
Within Groups	15.75	27	0.583333			
Total	16.75	35				

A.9 INITIALIZATION LENGTH VS.

The ANOVA tables of Initialization Length vs.

1. Carrier Frequency
2. End Pulse Width
3. Termination Length
4. Wakeup Length
5. Co-Header Length
6. Transition Time

are not included in this document as the variation in output for the mentioned factors is zero without any approximation.

Table A-145: Initialization Pulse Width vs. Maximum FSK Deviation ANOVA

	Max. FSK (kHz)					
Initialization Width (us)	1	2	3	4		
10	85	80	85	80		
11	80	85	80	80		
12	80	85	85	80		
13	80	85	85	80		
14	80	85	80	80		
15	85	80	85	80		
16	80	85	80	80		
17	80	85	85	80		
18	80	80	80	85		
19	85	80	85	80		
20	80	85	80	80		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	325	81.25	6.25		
Row 2	4	330	82.5	8.333333		
Row 3	4	325	81.25	6.25		
Row 4	4	330	82.5	8.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	6.25	3	2.083333	0.285714	0.834812	3.490295
Within Groups	87.5	12	7.291667			
Total	93.75	15				

Table A-146: Initialization Pulse Width vs. Minimum FSK Deviation ANOVA

	Min. FSK (kHz)			
Initialization Width (us)	1	2	3	4
10	25	20	20	20
11	20	20	20	20
12	25	20	20	25
13	20	20	20	20
14	25	20	20	20
15	20	20	20	20
16	25	20	20	25
17	25	20	20	20
18	20	20	20	20
19	25	20	20	25
20	25	20	20	20
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	85	21.25	6.25
Row 2	4	80	20	0
Row 3	4	90	22.5	8.333333
Row 4	4	80	20	0
Row 5	4	85	21.25	6.25
Row 6	4	80	20	0
Row 7	4	90	22.5	8.333333
Row 8	4	85	21.25	6.25
Row 9	4	80	20	0
Row 10	4	90	22.5	8.333333
Row 11	4	85	21.25	6.25

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	43.18182	10	4.318182	0.95	0.502762	2.132504
Within Groups	150	33	4.545455			
Total	193.1818	43				

Table A-147: Initialization Pulse Width vs. Maximum Wakeup Pulse Width ANOVA

	Max. Wakeup Pulse Width (us)					
Initialization Width (us)	1	2	3	4		
10	19	18	18	19		
11	19	19	19	18		
12	18	19	18	19		
13	19	18	19	19		
14	19	18	18	19		
15	18	19	18	19		
16	19	18	19	18		
17	19	19	19	18		
18	18	18	18	19		
19	19	18	19	18		
20	19	19	19	18		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	74	18.5	0.333333		
Row 2	4	75	18.75	0.25		
Row 3	4	74	18.5	0.333333		
Row 4	4	75	18.75	0.25		
Row 5	4	74	18.5	0.333333		
Row 6	4	74	18.5	0.333333		
Row 7	4	74	18.5	0.333333		
Row 8	4	75	18.75	0.25		
Row 9	4	73	18.25	0.25		
Row 10	4	74	18.5	0.333333		
Row 11	4	75	18.75	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.045455	10	0.104545	0.353846	0.957754	2.132504
Within Groups	9.75	33	0.295455			
Total	10.79545	43				

Table A-148: Initialization Pulse Width vs. Minimum Wakeup Pulse Width ANOVA

	Min. Wakeup Pulse Width (us)					
Initialization Width (us)	1	2	3	4		
10	14	15	15	14		
11	14	14	14	15		
12	14	15	14	15		
13	14	14	14	15		
14	15	14	14	14		
15	15	14	14	15		
16	14	15	15	14		
17	14	14	14	15		
18	14	14	14	15		
19	15	14	14	14		
20	14	14	14	15		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	58	14.5	0.333333		
Row 2	4	57	14.25	0.25		
Row 3	4	58	14.5	0.333333		
Row 4	4	57	14.25	0.25		
Row 5	4	57	14.25	0.25		
Row 6	4	58	14.5	0.333333		
Row 7	4	58	14.5	0.333333		
Row 8	4	57	14.25	0.25		
Row 9	4	57	14.25	0.25		
Row 10	4	57	14.25	0.25		
Row 11	4	57	14.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.636364	10	0.063636	0.227027	0.991543	2.132504
Within Groups	9.25	33	0.280303			
Total	9.886364	43				

Table A-149: Initialization Pulse Width vs. Maximum Co-Header Pulse Width ANOVA

	Max. CoHeader Pulse Width (us)					
Initialization Width (us)	1	2	3	4		
10	55	56	55	55		
11	56	56	55	55		
12	55	55	56	56		
13	55	55	56	56		
14	55	55	56	56		
15	55	56	55	55		
16	56	56	55	55		
17	55	55	56	56		
18	55	56	55	55		
19	56	56	55	55		
20	55	55	56	56		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	221	55.25	0.25		
Row 2	4	222	55.5	0.333333		
Row 3	4	222	55.5	0.333333		
Row 4	4	222	55.5	0.333333		
Row 5	4	222	55.5	0.333333		
Row 6	4	221	55.25	0.25		
Row 7	4	222	55.5	0.333333		
Row 8	4	222	55.5	0.333333		
Row 9	4	221	55.25	0.25		
Row 10	4	222	55.5	0.333333		
Row 11	4	222	55.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.545455	10	0.054545	0.17561	0.996972	2.132504
Within Groups	10.25	33	0.310606			
Total	10.79545	43				

Table A-150: Initialization Pulse Width vs. Minimum Co-Header Pulse Width ANOVA

	Min. CoHeader Pulse Width (us)			
Initialization Width (us)	1	2	3	4
10	48	47	48	47
11	47	48	47	48
12	48	47	47	47
13	47	48	47	48
14	48	47	48	47
15	47	48	47	48
16	48	47	47	47
17	47	48	47	48
18	48	47	48	47
19	47	48	47	48
20	48	47	47	47
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	190	47.5	0.333333
Row 2	4	190	47.5	0.333333
Row 3	4	189	47.25	0.25
Row 4	4	190	47.5	0.333333
Row 5	4	190	47.5	0.333333
Row 6	4	190	47.5	0.333333
Row 7	4	189	47.25	0.25
Row 8	4	190	47.5	0.333333
Row 9	4	190	47.5	0.333333
Row 10	4	190	47.5	0.333333
Row 11	4	189	47.25	0.25

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.545455	10	0.054545	0.17561	0.996972	2.132504
Within Groups	10.25	33	0.310606			
Total	10.79545	43				

Table A-151: Initialization Pulse Width vs. Maximum Preamble Pulse Width ANOVA

	Max. Preamble Pulse Width (us)			
Initialization Width (us)	1	2	3	4
10	67	66	66	67
11	66	66	66	67
12	67	66	66	66
13	66	67	66	66
14	67	66	66	67
15	66	66	66	67
16	67	66	66	66
17	67	66	66	67
18	66	67	66	66
19	67	66	66	67
20	66	66	66	67
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	266	66.5	0.333333
Row 2	4	265	66.25	0.25
Row 3	4	265	66.25	0.25
Row 4	4	265	66.25	0.25
Row 5	4	266	66.5	0.333333
Row 6	4	265	66.25	0.25
Row 7	4	265	66.25	0.25
Row 8	4	266	66.5	0.333333
Row 9	4	265	66.25	0.25
Row 10	4	266	66.5	0.333333
Row 11	4	265	66.25	0.25

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.636364	10	0.063636	0.227027	0.991543	2.132504
Within Groups	9.25	33	0.280303			
Total	9.886364	43				

Table A-152: Initialization Pulse Width vs. Minimum Preamble Pulse Width ANOVA

	Min. Preamble Pulse Width (us)			
Initialization Width (us)	1	2	3	4
10	54	55	55	55
11	55	54	55	54
12	54	55	54	55
13	54	55	55	55
14	55	54	55	54
15	55	54	55	55
16	54	55	55	55
17	55	54	55	55
18	54	55	55	55
19	55	54	55	54
20	54	55	54	55
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	219	54.75	0.25
Row 2	4	218	54.5	0.333333
Row 3	4	218	54.5	0.333333
Row 4	4	219	54.75	0.25
Row 5	4	218	54.5	0.333333
Row 6	4	219	54.75	0.25
Row 7	4	219	54.75	0.25
Row 8	4	219	54.75	0.25
Row 9	4	219	54.75	0.25
Row 10	4	218	54.5	0.333333
Row 11	4	218	54.5	0.333333

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.681818	10	0.068182	0.236842	0.990043	2.132504
Within Groups	9.5	33	0.287879			
Total	10.18182	43				

Table A-153: Initialization Pulse Width vs. Maximum Sync Pulse Width ANOVA

	Max. Sync Pulse Width (us)					
Initialization Width (us)	1	2	3	4		
10	57	56	56	57		
11	57	56	57	57		
12	56	56	56	57		
13	56	57	56	56		
14	57	56	56	57		
15	57	56	57	57		
16	57	56	56	56		
17	56	57	56	56		
18	57	56	56	57		
19	57	56	57	57		
20	56	56	56	57		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	226	56.5	0.333333		
Row 2	4	227	56.75	0.25		
Row 3	4	225	56.25	0.25		
Row 4	4	225	56.25	0.25		
Row 5	4	226	56.5	0.333333		
Row 6	4	227	56.75	0.25		
Row 7	4	225	56.25	0.25		
Row 8	4	225	56.25	0.25		
Row 9	4	226	56.5	0.333333		
Row 10	4	227	56.75	0.25		
Row 11	4	225	56.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.909091	10	0.190909	0.7	0.717439	2.132504
Within Groups	9	33	0.272727			
Total	10.90909	43				

Table A-154: Initialization Pulse Width vs. Minimum Sync Pulse Width ANOVA

	Min. Sync Pulse Width (us)					
Initialization Width (us)	1	2	3	4		
10	52	52	51	51		
11	51	51	51	51		
12	52	51	51	51		
13	52	51	51	51		
14	52	52	51	51		
15	51	51	51	51		
16	52	51	51	51		
17	52	52	51	51		
18	51	52	51	51		
19	52	52	51	51		
20	51	51	51	51		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	206	51.5	0.333333		
Row 2	4	204	51	0		
Row 3	4	205	51.25	0.25		
Row 4	4	205	51.25	0.25		
Row 5	4	206	51.5	0.333333		
Row 6	4	204	51	0		
Row 7	4	205	51.25	0.25		
Row 8	4	206	51.5	0.333333		
Row 9	4	205	51.25	0.25		
Row 10	4	206	51.5	0.333333		
Row 11	4	204	51	0		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.727273	10	0.172727	0.814286	0.617121	2.132504
Within Groups	7	33	0.212121			
Total	8.727273	43				

Table A-155: Initialization Pulse Width vs. Maximum Data Pulse Width ANOVA

	Max. Data Width (us)					
Initialization Width (us)	1	2	3	4		
10	39	40	40	39		
11	40	40	40	40		
12	39	39	40	39		
13	39	39	40	40		
14	39	40	40	39		
15	40	40	40	40		
16	39	39	40	39		
17	39	39	40	40		
18	39	40	40	39		
19	40	40	40	40		
20	39	39	40	39		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	158	39.5	0.333333		
Row 2	4	160	40	0		
Row 3	4	157	39.25	0.25		
Row 4	4	158	39.5	0.333333		
Row 5	4	158	39.5	0.333333		
Row 6	4	160	40	0		
Row 7	4	157	39.25	0.25		
Row 8	4	158	39.5	0.333333		
Row 9	4	158	39.5	0.333333		
Row 10	4	160	40	0		
Row 11	4	157	39.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.545455	10	0.354545	1.613793	0.14596	2.132504
Within Groups	7.25	33	0.219697			
Total	10.79545	43				

Table A-156: Initialization Pulse Width vs. Minimum Data Pulse Width ANOVA

	Min. data Width (us)			
Initialization Width (us)	1	2	3	4
10	30	30	30	31
11	30	30	30	30
12	31	30	30	30
13	30	30	30	30
14	30	30	30	31
15	30	30	30	30
16	31	30	30	30
17	30	30	30	31
18	30	30	30	30
19	30	30	30	31
20	30	30	30	30
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	121	30.25	0.25
Row 2	4	120	30	0
Row 3	4	121	30.25	0.25
Row 4	4	120	30	0
Row 5	4	121	30.25	0.25
Row 6	4	120	30	0
Row 7	4	121	30.25	0.25
Row 8	4	121	30.25	0.25
Row 9	4	120	30	0
Row 10	4	121	30.25	0.25
Row 11	4	120	30	0

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.681818	10	0.068182	0.5	0.877567	2.132504
Within Groups	4.5	33	0.136364			
Total	5.181818	43				

Table A-157: Initialization PW vs. Maximum Time between Wakeup & Command ANOVA

	Max. Time bet Wakeup & Command			
Initialization Width (us)	1	2	3	4
10	29	29	29	29
11	28	29	29	28
12	29	29	28	28
13	28	29	28	28
14	29	29	29	29
15	28	29	29	28
16	29	29	28	28
17	29	29	28	28
18	29	29	28	28
19	29	29	28	28
20	29	29	28	28
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	116	29	0
Row 2	4	114	28.5	0.333333
Row 3	4	114	28.5	0.333333
Row 4	4	113	28.25	0.25
Row 5	4	116	29	0
Row 6	4	114	28.5	0.333333
Row 7	4	114	28.5	0.333333
Row 8	4	114	28.5	0.333333
Row 9	4	114	28.5	0.333333
Row 10	4	114	28.5	0.333333
Row 11	4	114	28.5	0.333333

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.045455	10	0.204545	0.771429	0.654689	2.132504
Within Groups	8.75	33	0.265152			
Total	10.79545	43				

Table A-158: Initialization PW vs. Minimum Time between Wakeup & Command ANOVA

	Min. Time bet Wakeup & Command (us)			
Initialization Width (us)	1	2	3	4
10	1	1	1	1
11	1	1	1	1
12	1	1	1	1
13	1	1	1	1
14	1	1	1	1
15	1	1	1	1
16	1	1	1	1
17	1	1	1	1
18	1	1	1	1
19	1	1	1	1
20	1	1	1	1

Table A-159: Initialization Pulse Width vs. Tag Awake Time ANOVA

	Tag Awake Time (sec)					
Initialization Width (us)	1	2	3	4		
10	29	29	29	28		
11	29	28	29	28		
12	29	29	29	29		
13	29	28	29	29		
14	29	29	29	28		
15	29	28	29	28		
16	29	29	29	29		
17	29	30	29	30		
18	29	31	29	31		
19	29	32	29	32		
20	29	33	29	33		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	115	28.75	0.25		
Row 2	4	114	28.5	0.333333		
Row 3	4	116	29	0		
Row 4	4	115	28.75	0.25		
Row 5	4	115	28.75	0.25		
Row 6	4	114	28.5	0.333333		
Row 7	4	116	29	0		
Row 8	4	118	29.5	0.333333		
Row 9	4	120	30	1.333333		
Row 10	4	122	30.5	3		
Row 11	4	124	31	5.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	28.90909	10	2.890909	2.785401	0.012959	2.132504
Within Groups	34.25	33	1.037879			
Total	63.15909	43				

Table A-160: Initialization Pulse Width vs. Minimum Number of Preambles ANOVA

	Min. No. of Preambles					
Initialization Width (us)	1	2	3	4		
10	9	8	8	10		
11	8	9	9	8		
12	9	8	9	8		
13	8	9	9	9		
14	9	8	8	10		
15	8	9	9	8		
16	9	8	9	9		
17	8	9	9	8		
18	9	8	8	10		
19	8	9	9	8		
20	9	8	9	8		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	35	8.75	0.916667		
Row 2	4	34	8.5	0.333333		
Row 3	4	34	8.5	0.333333		
Row 4	4	35	8.75	0.25		
Row 5	4	35	8.75	0.916667		
Row 6	4	34	8.5	0.333333		
Row 7	4	35	8.75	0.25		
Row 8	4	34	8.5	0.333333		
Row 9	4	35	8.75	0.916667		
Row 10	4	34	8.5	0.333333		
Row 11	4	34	8.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.681818	10	0.068182	0.142857	0.998726	2.132504
Within Groups	15.75	33	0.477273			
Total	16.43182	43				

A.10 TERMINATION LENGTH VS.

The ANOVA tables of Termination Length vs.

1. Carrier Frequency
2. End Pulse Width
3. Initialization Length
4. Wakeup Length
5. Co-Header Length
6. Transition Time

are not included in this document as the variation in output for the mentioned factors is zero without any approximation.

Table A-161: Termination Pulse Width vs. Maximum FSK Deviation ANOVA

	Max. FSK (kHz)			
Termination Width (us)	1	2	3	4
10	85	80	85	80
11	80	85	80	80
12	80	85	85	80
13	80	85	85	80
14	80	85	80	80
15	85	80	85	80
16	80	85	80	80
17	80	85	85	80
18	80	80	80	85
19	85	80	85	80
20	80	85	80	80
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	330	82.5	8.333333
Row 2	4	325	81.25	6.25
Row 3	4	330	82.5	8.333333
Row 4	4	330	82.5	8.333333
Row 5	4	325	81.25	6.25
Row 6	4	330	82.5	8.333333
Row 7	4	325	81.25	6.25
Row 8	4	330	82.5	8.333333
Row 9	4	325	81.25	6.25
Row 10	4	330	82.5	8.333333
Row 11	4	325	81.25	6.25

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	17.04545	10	1.704545	0.230769	0.99099	2.132504
Within Groups	243.75	33	7.386364			
Total	260.7955	43				

Table A-162: Termination Pulse Width vs. Minimum FSK Deviation ANOVA

	Min. FSK (kHz)					
Termination Width (us)	1	2	3	4		
10	25	20	20	20		
11	20	20	20	20		
12	25	20	20	25		
13	20	20	20	20		
14	25	20	20	20		
15	20	20	20	20		
16	25	20	20	25		
17	25	20	20	20		
18	20	20	20	20		
19	25	20	20	25		
20	25	20	20	20		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	85	21.25	6.25		
Row 2	4	80	20	0		
Row 3	4	90	22.5	8.333333		
Row 4	4	80	20	0		
Row 5	4	85	21.25	6.25		
Row 6	4	80	20	0		
Row 7	4	90	22.5	8.333333		
Row 8	4	85	21.25	6.25		
Row 9	4	80	20	0		
Row 10	4	90	22.5	8.333333		
Row 11	4	85	21.25	6.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	43.18182	10	4.318182	0.95	0.502762	2.132504
Within Groups	150	33	4.545455			
Total	193.1818	43				

Table A-163: Termination Pulse Width vs. Maximum Wakeup Pulse Width ANOVA

	Max. Wakeup Pulse Width (us)					
Termination Width (us)	1	2	3	4		
10	19	18	18	19		
11	19	19	19	18		
12	18	19	18	19		
13	19	18	19	19		
14	19	18	18	19		
15	18	19	18	19		
16	19	18	19	18		
17	19	19	19	18		
18	18	18	18	19		
19	19	18	19	18		
20	19	19	19	18		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	74	18.5	0.333333		
Row 2	4	75	18.75	0.25		
Row 3	4	74	18.5	0.333333		
Row 4	4	75	18.75	0.25		
Row 5	4	74	18.5	0.333333		
Row 6	4	74	18.5	0.333333		
Row 7	4	74	18.5	0.333333		
Row 8	4	75	18.75	0.25		
Row 9	4	73	18.25	0.25		
Row 10	4	74	18.5	0.333333		
Row 11	4	75	18.75	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.045455	10	0.104545	0.353846	0.957754	2.132504
Within Groups	9.75	33	0.295455			
Total	10.79545	43				

Table A-164: Termination Pulse Width vs. Minimum Wakeup Pulse Width ANOVA

	Min. Wakeup Pulse Width (us)					
Termination Width (us)	1	2	3	4		
10	14	15	15	14		
11	14	14	14	15		
12	14	15	14	15		
13	14	14	14	15		
14	15	14	14	14		
15	15	14	14	15		
16	14	15	15	14		
17	14	14	14	15		
18	14	14	14	15		
19	15	14	14	14		
20	14	14	14	15		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	58	14.5	0.333333		
Row 2	4	57	14.25	0.25		
Row 3	4	58	14.5	0.333333		
Row 4	4	57	14.25	0.25		
Row 5	4	57	14.25	0.25		
Row 6	4	58	14.5	0.333333		
Row 7	4	58	14.5	0.333333		
Row 8	4	57	14.25	0.25		
Row 9	4	57	14.25	0.25		
Row 10	4	57	14.25	0.25		
Row 11	4	57	14.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.636364	10	0.063636	0.227027	0.991543	2.132504
Within Groups	9.25	33	0.280303			
Total	9.886364	43				

Table A-165: Termination Pulse Width vs. Maximum Co-Header Pulse Width ANOVA

	Max. CoHeader Pulse Width (us)					
Termination Width (us)	1	2	3	4		
10	55	56	55	55		
11	56	56	55	55		
12	55	55	56	56		
13	55	55	56	56		
14	55	55	56	56		
15	55	56	55	55		
16	56	56	55	55		
17	55	55	56	56		
18	55	56	55	55		
19	56	56	55	55		
20	55	55	56	56		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	221	55.25	0.25		
Row 2	4	222	55.5	0.333333		
Row 3	4	222	55.5	0.333333		
Row 4	4	222	55.5	0.333333		
Row 5	4	222	55.5	0.333333		
Row 6	4	221	55.25	0.25		
Row 7	4	222	55.5	0.333333		
Row 8	4	222	55.5	0.333333		
Row 9	4	221	55.25	0.25		
Row 10	4	222	55.5	0.333333		
Row 11	4	222	55.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.545455	10	0.054545	0.17561	0.996972	2.132504
Within Groups	10.25	33	0.310606			
Total	10.79545	43				

Table A-166: Termination Pulse Width vs. Minimum Co-Header Pulse Width ANOVA

	Min. CoHeader Pulse Width (us)					
Termination Width (us)	1	2	3	4		
10	48	47	48	47		
11	47	48	47	48		
12	48	47	47	47		
13	47	48	47	48		
14	48	47	48	47		
15	47	48	47	48		
16	48	47	47	47		
17	47	48	47	48		
18	48	47	48	47		
19	47	48	47	48		
20	48	47	47	47		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	190	47.5	0.333333		
Row 2	4	190	47.5	0.333333		
Row 3	4	189	47.25	0.25		
Row 4	4	190	47.5	0.333333		
Row 5	4	190	47.5	0.333333		
Row 6	4	190	47.5	0.333333		
Row 7	4	189	47.25	0.25		
Row 8	4	190	47.5	0.333333		
Row 9	4	190	47.5	0.333333		
Row 10	4	190	47.5	0.333333		
Row 11	4	189	47.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.545455	10	0.054545	0.17561	0.996972	2.132504
Within Groups	10.25	33	0.310606			
Total	10.79545	43				

Table A-167: Termination Pulse Width vs. Maximum Preamble Pulse Width ANOVA

	Max. Preamble Pulse Width (us)					
Termination Width (us)	1	2	3	4		
10	67	66	66	67		
11	66	66	66	67		
12	67	66	66	66		
13	66	67	66	66		
14	67	66	66	67		
15	66	66	66	67		
16	67	66	66	66		
17	67	66	66	67		
18	66	67	66	66		
19	67	66	66	67		
20	66	66	66	67		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	266	66.5	0.333333		
Row 2	4	265	66.25	0.25		
Row 3	4	265	66.25	0.25		
Row 4	4	265	66.25	0.25		
Row 5	4	266	66.5	0.333333		
Row 6	4	265	66.25	0.25		
Row 7	4	265	66.25	0.25		
Row 8	4	266	66.5	0.333333		
Row 9	4	265	66.25	0.25		
Row 10	4	266	66.5	0.333333		
Row 11	4	265	66.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.636364	10	0.063636	0.227027	0.991543	2.132504
Within Groups	9.25	33	0.280303			
Total	9.886364	43				

Table A-168: Termination Pulse Width vs. Minimum Preamble Pulse Width ANOVA

	Min. Preamble Pulse Width (us)					
Termination Width (us)	1	2	3	4		
10	54	55	55	55		
11	55	54	55	54		
12	54	55	54	55		
13	54	55	55	55		
14	55	54	55	54		
15	55	54	55	55		
16	54	55	55	55		
17	55	54	55	55		
18	54	55	55	55		
19	55	54	55	54		
20	54	55	54	55		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	219	54.75	0.25		
Row 2	4	218	54.5	0.333333		
Row 3	4	218	54.5	0.333333		
Row 4	4	219	54.75	0.25		
Row 5	4	218	54.5	0.333333		
Row 6	4	219	54.75	0.25		
Row 7	4	219	54.75	0.25		
Row 8	4	219	54.75	0.25		
Row 9	4	219	54.75	0.25		
Row 10	4	218	54.5	0.333333		
Row 11	4	218	54.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.681818	10	0.068182	0.236842	0.990043	2.132504
Within Groups	9.5	33	0.287879			
Total	10.18182	43				

Table A-169: Termination Pulse Width vs. Maximum Sync Pulse Width ANOVA

	Max. Sync Pulse Width (us)					
Termination Width (us)	1	2	3	4		
10	57	56	56	57		
11	57	56	57	57		
12	56	56	56	57		
13	56	57	56	56		
14	57	56	56	57		
15	57	56	57	57		
16	57	56	56	56		
17	56	57	56	56		
18	57	56	56	57		
19	57	56	57	57		
20	56	56	56	57		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	226	56.5	0.333333		
Row 2	4	227	56.75	0.25		
Row 3	4	225	56.25	0.25		
Row 4	4	225	56.25	0.25		
Row 5	4	226	56.5	0.333333		
Row 6	4	227	56.75	0.25		
Row 7	4	225	56.25	0.25		
Row 8	4	225	56.25	0.25		
Row 9	4	226	56.5	0.333333		
Row 10	4	227	56.75	0.25		
Row 11	4	225	56.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.909091	10	0.190909	0.7	0.717439	2.132504
Within Groups	9	33	0.272727			
Total	10.90909	43				

Table A-170: Termination Pulse Width vs. Minimum Sync Pulse Width ANOVA

	Max. Sync Pulse Width (us)					
Termination Width (us)	1	2	3	4		
10	52	52	51	51		
11	51	51	51	51		
12	52	51	51	51		
13	52	51	51	51		
14	52	52	51	51		
15	51	51	51	51		
16	52	51	51	51		
17	52	52	51	51		
18	51	52	51	51		
19	52	52	51	51		
20	51	51	51	51		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	206	51.5	0.333333		
Row 2	4	204	51	0		
Row 3	4	205	51.25	0.25		
Row 4	4	205	51.25	0.25		
Row 5	4	206	51.5	0.333333		
Row 6	4	204	51	0		
Row 7	4	205	51.25	0.25		
Row 8	4	206	51.5	0.333333		
Row 9	4	205	51.25	0.25		
Row 10	4	206	51.5	0.333333		
Row 11	4	204	51	0		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.727273	10	0.172727	0.814286	0.617121	2.132504
Within Groups	7	33	0.212121			
Total	8.727273	43				

Table A-171: Termination Pulse Width vs. Maximum Data Pulse Width ANOVA

	Max. Data Width (us)					
Termination Width (us)	1	2	3	4		
10	39	40	40	39		
11	40	40	40	40		
12	39	39	40	39		
13	39	39	40	40		
14	39	40	40	39		
15	40	40	40	40		
16	39	39	40	39		
17	39	39	40	40		
18	39	40	40	39		
19	40	40	40	40		
20	39	39	40	39		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	158	39.5	0.333333		
Row 2	4	160	40	0		
Row 3	4	157	39.25	0.25		
Row 4	4	158	39.5	0.333333		
Row 5	4	158	39.5	0.333333		
Row 6	4	160	40	0		
Row 7	4	157	39.25	0.25		
Row 8	4	158	39.5	0.333333		
Row 9	4	158	39.5	0.333333		
Row 10	4	160	40	0		
Row 11	4	157	39.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	3.545455	10	0.354545	1.613793	0.14596	2.132504
Within Groups	7.25	33	0.219697			
Total	10.79545	43				

Table A-172: Termination Pulse Width vs. Minimum Data Pulse Width ANOVA

	Min. data Width (us)			
Termination Width (us)	1	2	3	4
10	30	30	30	31
11	30	30	30	30
12	31	30	30	30
13	30	30	30	30
14	30	30	30	31
15	30	30	30	30
16	31	30	30	30
17	30	30	30	31
18	30	30	30	30
19	30	30	30	31
20	30	30	30	30
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	121	30.25	0.25
Row 2	4	120	30	0
Row 3	4	121	30.25	0.25
Row 4	4	120	30	0
Row 5	4	121	30.25	0.25
Row 6	4	120	30	0
Row 7	4	121	30.25	0.25
Row 8	4	121	30.25	0.25
Row 9	4	120	30	0
Row 10	4	121	30.25	0.25
Row 11	4	120	30	0

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.681818	10	0.068182	0.5	0.877567	2.132504
Within Groups	4.5	33	0.136364			
Total	5.181818	43				

Table A-173: Termination PW vs. Maximum Time between Wakeup & Command ANOVA

	Max. Time bet Wakeup & Command			
Termination Width (us)	1	2	3	4
10	29	29	29	29
11	28	29	29	28
12	29	29	28	28
13	28	29	28	28
14	29	29	29	29
15	28	29	29	28
16	29	29	28	28
17	29	29	28	28
18	29	29	28	28
19	29	29	28	28
20	29	29	28	28
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	116	29	0
Row 2	4	114	28.5	0.333333
Row 3	4	114	28.5	0.333333
Row 4	4	113	28.25	0.25
Row 5	4	116	29	0
Row 6	4	114	28.5	0.333333
Row 7	4	114	28.5	0.333333
Row 8	4	114	28.5	0.333333
Row 9	4	114	28.5	0.333333
Row 10	4	114	28.5	0.333333
Row 11	4	114	28.5	0.333333

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.045455	10	0.204545	0.771429	0.654689	2.132504
Within Groups	8.75	33	0.265152			
Total	10.79545	43				

Table A-174: Termination PW vs. Minimum Time between Wakeup & Command ANOVA

	Min. Time bet Wakeup & Command (us)			
Termination Width (us)	1	2	3	4
10	1	1	1	1
11	1	1	1	1
12	1	1	1	1
13	1	1	1	1
14	1	1	1	1
15	1	1	1	1
16	1	1	1	1
17	1	1	1	1
18	1	1	1	1
19	1	1	1	1
20	1	1	1	1

Table A-175: Termination Pulse Width vs. Tag Awake Time ANOVA

	Tag Awake Time (sec)					
Termination Width (us)	1	2	3	4		
10	29	29	29	28		
11	29	28	29	28		
12	29	29	29	29		
13	29	28	29	29		
14	29	29	29	28		
15	29	28	29	28		
16	29	29	29	29		
17	29	30	29	30		
18	29	31	29	31		
19	29	32	29	32		
20	29	33	29	33		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	115	28.75	0.25		
Row 2	4	114	28.5	0.333333		
Row 3	4	116	29	0		
Row 4	4	115	28.75	0.25		
Row 5	4	115	28.75	0.25		
Row 6	4	114	28.5	0.333333		
Row 7	4	116	29	0		
Row 8	4	118	29.5	0.333333		
Row 9	4	120	30	1.333333		
Row 10	4	122	30.5	3		
Row 11	4	124	31	5.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	28.90909	10	2.890909	2.785401	0.012959	2.132504
Within Groups	34.25	33	1.037879			
Total	63.15909	43				

Table A-176: Termination Pulse Width vs. Minimum Number of Preambles ANOVA

	Min. No. of Preambles						
Termination Width (us)	1	2	3	4			
10	9	8	8	10			
11	8	9	9	8			
12	9	8	9	8			
13	8	9	9	9			
14	9	8	8	10			
15	8	9	9	8			
16	9	8	9	9			
17	8	9	9	8			
18	9	8	8	10			
19	8	9	9	8			
20	9	8	9	8			
SUMMARY							
Groups	Count	Sum	Average	Variance			
Row 1	4	35	8.75	0.916667			
Row 2	4	34	8.5	0.333333			
Row 3	4	34	8.5	0.333333			
Row 4	4	35	8.75	0.25			
Row 5	4	35	8.75	0.916667			
Row 6	4	34	8.5	0.333333			
Row 7	4	35	8.75	0.25			
Row 8	4	34	8.5	0.333333			
Row 9	4	35	8.75	0.916667			
Row 10	4	34	8.5	0.333333			
Row 11	4	34	8.5	0.333333			
ANOVA							
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*	
Between Groups	0.681818	10	0.068182	0.142857	0.998726	2.132504	
Within Groups	15.75	33	0.477273				
Total	16.43182	43					

A.11 WAKEUP LENGTH VS.

The ANOVA tables of Wakeup Length vs.

1. Carrier Frequency
2. End Pulse Width
3. Initialization Length
4. Termination Length
5. Co-Header Length
6. Transition Time

are not included in this document as the variation in output for the mentioned factors is zero without any approximation.

Table A-177: Wakeup Length vs. Maximum FSK Deviation ANOVA

	Max. FSK (kHz)			
Wakeup Length (sec)	1	2	3	4
1	85	80	85	80
2	80	85	80	80
3	80	85	85	80
4	80	85	85	80
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	330	82.5	8.333333
Row 2	4	325	81.25	6.25
Row 3	4	330	82.5	8.333333
Row 4	4	330	82.5	8.333333

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	4.6875	3	1.5625	0.2	0.894377	3.490295
Within Groups	93.75	12	7.8125			
Total	98.4375	15				

Table A-178: Wakeup Length vs. Minimum FSK Deviation ANOVA

	Min. FSK (kHz)			
Wakeup Length (sec)	1	2	3	4
1	25	20	20	20
2	20	20	20	20
3	25	20	20	25
4	20	20	20	20
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	85	21.25	6.25
Row 2	4	80	20	0
Row 3	4	90	22.5	8.333333
Row 4	4	80	20	0

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	17.1875	3	5.729167	1.571429	0.24757	3.490295
Within Groups	43.75	12	3.645833			
Total	60.9375	15				

Table A-179: Wakeup Length vs. Maximum Wakeup Pulse Width ANOVA

	Max. Wakeup Pulse Width (us)					
Wakeup Length (sec)	1	2	3	4		
1	19	18	18	19		
2	19	19	19	18		
3	18	19	18	19		
4	19	18	19	19		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	74	18.5	0.333333		
Row 2	4	75	18.75	0.25		
Row 3	4	74	18.5	0.333333		
Row 4	4	75	18.75	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.25	3	0.083333	0.285714	0.834812	3.490295
Within Groups	3.5	12	0.291667			
Total	3.75	15				

Table A-180: Wakeup Length vs. Minimum Wakeup Pulse Width ANOVA

	Min. Wakeup Pulse Width (us)					
Wakeup Length (sec)	1	2	3	4		
1	14	15	15	14		
2	14	14	14	15		
3	14	15	14	15		
4	14	14	14	15		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	58	14.5	0.333333		
Row 2	4	57	14.25	0.25		
Row 3	4	58	14.5	0.333333		
Row 4	4	57	14.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.25	3	0.083333	0.285714	0.834812	3.490295
Within Groups	3.5	12	0.291667			
Total	3.75	15				

Table A-181: Wakeup Length vs. Maximum Co-Header Pulse Width ANOVA

	Max. CoHeader Pulse Width (us)					
Wakeup Length (sec)	1	2	3	4		
1	55	56	55	55		
2	56	56	55	55		
3	55	55	56	56		
4	55	55	56	56		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	221	55.25	0.25		
Row 2	4	222	55.5	0.333333		
Row 3	4	222	55.5	0.333333		
Row 4	4	222	55.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.1875	3	0.0625	0.2	0.894377	3.490295
Within Groups	3.75	12	0.3125			
Total	3.9375	15				

Table A-182: Wakeup Length vs. Minimum Co-Header Pulse Width ANOVA

	Min. CoHeader Pulse Width (us)					
Wakeup Length (sec)	1	2	3	4		
1	48	47	48	47		
2	47	48	47	48		
3	48	47	47	47		
4	47	48	47	48		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	190	47.5	0.333333		
Row 2	4	190	47.5	0.333333		
Row 3	4	189	47.25	0.25		
Row 4	4	190	47.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.1875	3	0.0625	0.2	0.894377	3.490295
Within Groups	3.75	12	0.3125			
Total	3.9375	15				

Table A-183: Wakeup Length vs. Maximum Preamble Pulse Width ANOVA

	Max. Preamble Pulse Width (us)					
Wakeup Length (sec)	1	2	3	4		
1	67	66	66	67		
2	66	66	66	67		
3	67	66	66	66		
4	66	67	66	66		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	266	66.5	0.333333		
Row 2	4	265	66.25	0.25		
Row 3	4	265	66.25	0.25		
Row 4	4	265	66.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.1875	3	0.0625	0.230769	0.873191	3.490295
Within Groups	3.25	12	0.270833			
Total	3.4375	15				

Table A-184: Wakeup Length vs. Minimum Preamble Pulse Width ANOVA

	Min. Preamble Pulse Width (us)					
Wakeup Length (sec)	1	2	3	4		
1	54	55	55	55		
2	55	54	55	54		
3	54	55	54	55		
4	54	55	55	55		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	219	54.75	0.25		
Row 2	4	218	54.5	0.333333		
Row 3	4	218	54.5	0.333333		
Row 4	4	219	54.75	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.25	3	0.083333	0.285714	0.834812	3.490295
Within Groups	3.5	12	0.291667			
Total	3.75	15				

Table A-185: Wakeup Length vs. Maximum Sync Pulse Width ANOVA

	Max. Sync Pulse Width (us)					
Wakeup Length (sec)	1	2	3	4		
1	57	56	56	57		
2	57	56	57	57		
3	56	56	56	57		
4	56	57	56	56		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	226	56.5	0.333333		
Row 2	4	227	56.75	0.25		
Row 3	4	225	56.25	0.25		
Row 4	4	225	56.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.6875	3	0.229167	0.846154	0.494769	3.490295
Within Groups	3.25	12	0.270833			
Total	3.9375	15				

Table A-186: Wakeup Length vs. Minimum Sync Pulse Width ANOVA

	Max. Sync Pulse Width (us)					
Wakeup Length (sec)	1	2	3	4		
1	52	52	51	51		
2	51	51	51	51		
3	52	51	51	51		
4	52	51	51	51		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	206	51.5	0.333333		
Row 2	4	204	51	0		
Row 3	4	205	51.25	0.25		
Row 4	4	205	51.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.5	3	0.166667	0.8	0.517404	3.490295
Within Groups	2.5	12	0.208333			
Total	3	15				

Table A-187: Wakeup Length vs. Maximum Data Pulse Width ANOVA

	Max. Data Width (us)					
Wakeup Length (sec)	1	2	3	4		
1	39	40	40	39		
2	40	40	40	40		
3	39	39	40	39		
4	39	39	40	40		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	158	39.5	0.333333		
Row 2	4	160	40	0		
Row 3	4	157	39.25	0.25		
Row 4	4	158	39.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.1875	3	0.395833	1.727273	0.214486	3.490295
Within Groups	2.75	12	0.229167			
Total	3.9375	15				

Table A-188: Wakeup Length vs. Minimum Data Pulse Width ANOVA

	Min. data Width (us)					
Wakeup Length (sec)	1	2	3	4		
1	30	30	30	31		
2	30	30	30	30		
3	31	30	30	30		
4	30	30	30	30		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	121	30.25	0.25		
Row 2	4	120	30	0		
Row 3	4	121	30.25	0.25		
Row 4	4	120	30	0		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.25	3	0.083333	0.666667	0.588471	3.490295
Within Groups	1.5	12	0.125			
Total	1.75	15				

Table A-189: Wakeup Length vs. Maximum Time between Wakeup & Command ANOVA

	Max. Time bet Wakeup & Command					
Wakeup Length (sec)	1	2	3	4		
1	29	29	29	29		
2	28	29	29	28		
3	29	29	28	28		
4	28	29	28	28		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	116	29	0		
Row 2	4	114	28.5	0.333333		
Row 3	4	114	28.5	0.333333		
Row 4	4	113	28.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.1875	3	0.395833	1.727273	0.214486	3.490295
Within Groups	2.75	12	0.229167			
Total	3.9375	15				

Table A-190: Wakeup Length vs. Minimum Time between Wakeup & Command ANOVA

	Min. Time bet Wakeup & Command (us)			
Wakeup Length (sec)	1	2	3	4
1	1	1	1	1
2	1	1	1	1
3	1	1	1	1
4	1	1	1	1

Table A-191: Wakeup Length vs. Tag Awake Time ANOVA

	Tag Awake Time (sec)					
Wakeup Length (sec)	1	2	3	4		
1	29	29	29	28		
2	29	28	29	28		
3	29	29	29	29		
4	29	28	29	29		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	115	28.75	0.25		
Row 2	4	114	28.5	0.333333		
Row 3	4	116	29	0		
Row 4	4	115	28.75	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.5	3	0.166667	0.8	0.517404	3.490295
Within Groups	2.5	12	0.208333			
Total	3	15				

Table A-192: Wakeup Length vs. Minimum Number of Preambles ANOVA

	Min. No. of Preambles					
Wakeup Length (sec)	1	2	3	4		
1	9	8	8	10		
2	8	9	9	8		
3	9	8	9	8		
4	8	9	9	9		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	35	8.75	0.916667		
Row 2	4	34	8.5	0.333333		
Row 3	4	34	8.5	0.333333		
Row 4	4	35	8.75	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.25	3	0.083333	0.181818	0.906692	3.490295
Within Groups	5.5	12	0.458333			
Total	5.75	15				

A.12 CO-HEADER LENGTH VS.

The ANOVA tables of Co-Header Length vs.

1. Carrier Frequency
2. End Pulse Width
3. Initialization Length
4. Termination Length
5. Wakeup Length
6. Transition Time

are not included in this document as the variation in output for the mentioned factors is zero without any approximation.

Table A-193: Co-Header Length vs. Maximum FSK Deviation ANOVA

	Max. FSK (kHz)					
CoHeader Length (ms)	1	2	3	4		
90	85	80	85	80		
95	80	85	80	80		
100	80	85	85	80		
105	80	85	85	80		
110	80	85	80	80		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	330	82.5	8.333333		
Row 2	4	325	81.25	6.25		
Row 3	4	330	82.5	8.333333		
Row 4	4	330	82.5	8.333333		
Row 5	4	325	81.25	6.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7.5	4	1.875	0.25	0.905175	3.055568
Within Groups	112.5	15	7.5			
Total	120	19				

Table A-194: Co-Header Length vs. Minimum FSK Deviation ANOVA

	Min. FSK (kHz)					
CoHeader Length (ms)	1	2	3	4		
90	25	20	20	20		
95	20	20	20	20		
100	25	20	20	25		
105	20	20	20	20		
110	25	20	20	20		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	85	21.25	6.25		
Row 2	4	80	20	0		
Row 3	4	90	22.5	8.333333		
Row 4	4	80	20	0		
Row 5	4	85	21.25	6.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	17.5	4	4.375	1.05	0.414603	3.055568
Within Groups	62.5	15	4.166667			
Total	80	19				

Table A-195: Co-Header Length vs. Maximum Wakeup Pulse Width ANOVA

	Max. Wakeup Pulse Width (us)					
CoHeader Length (ms)	1	2	3	4		
90	19	18	18	19		
95	19	19	19	18		
100	18	19	18	19		
105	19	18	19	19		
110	18	19	18	19		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	74	18.5	0.333333		
Row 2	4	75	18.75	0.25		
Row 3	4	74	18.5	0.333333		
Row 4	4	75	18.75	0.25		
Row 5	4	74	18.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.25	0.905175	3.055568
Within Groups	4.5	15	0.3			
Total	4.8	19				

Table A-196: Co-Header Length vs. Minimum Wakeup Pulse Width ANOVA

	Min. Wakeup Pulse Width (us)					
CoHeader Length (ms)	1	2	3	4		
90	14	15	15	14		
95	14	14	14	15		
100	14	15	14	15		
105	14	14	14	15		
110	14	15	14	15		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	58	14.5	0.333333		
Row 2	4	57	14.25	0.25		
Row 3	4	58	14.5	0.333333		
Row 4	4	57	14.25	0.25		
Row 5	4	58	14.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.25	0.905175	3.055568
Within Groups	4.5	15	0.3			
Total	4.8	19				

Table A-197: Co-Header Length vs. Maximum Co-Header Pulse Width ANOVA

	Max. CoHeader Pulse Width (us)					
CoHeader Length (ms)	1	2	3	4		
90	55	56	55	55		
95	56	56	55	55		
100	55	55	56	56		
105	55	55	56	56		
110	55	56	55	55		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	221	55.25	0.25		
Row 2	4	222	55.5	0.333333		
Row 3	4	222	55.5	0.333333		
Row 4	4	222	55.5	0.333333		
Row 5	4	221	55.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.25	0.905175	3.055568
Within Groups	4.5	15	0.3			
Total	4.8	19				

Table A-198: Co-Header Length vs. Minimum Co-Header Pulse Width ANOVA

	Min. CoHeader Pulse Width (us)					
CoHeader Length (ms)	1	2	3	4		
90	48	47	48	47		
95	47	48	47	48		
100	48	47	47	47		
105	47	48	47	48		
110	48	47	47	47		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	190	47.5	0.333333		
Row 2	4	190	47.5	0.333333		
Row 3	4	189	47.25	0.25		
Row 4	4	190	47.5	0.333333		
Row 5	4	189	47.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.25	0.905175	3.055568
Within Groups	4.5	15	0.3			
Total	4.8	19				

Table A-199: Co-Header Length vs. Maximum Preamble Pulse Width ANOVA

	Max. Preamble Pulse Width (us)					
CoHeader Length (ms)	1	2	3	4		
90	67	66	66	67		
95	66	66	66	67		
100	67	66	66	66		
105	66	67	66	66		
110	66	66	66	67		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	266	66.5	0.333333		
Row 2	4	265	66.25	0.25		
Row 3	4	265	66.25	0.25		
Row 4	4	265	66.25	0.25		
Row 5	4	265	66.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.2	4	0.05	0.1875	0.941252	3.055568
Within Groups	4	15	0.266667			
Total	4.2	19				

Table A-200: Co-Header Length vs. Minimum Preamble Pulse Width ANOVA

	Min. Preamble Pulse Width (us)					
CoHeader Length (ms)	1	2	3	4		
90	54	55	55	55		
95	55	54	55	54		
100	54	55	54	55		
105	54	55	55	55		
110	54	55	55	55		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	219	54.75	0.25		
Row 2	4	218	54.5	0.333333		
Row 3	4	218	54.5	0.333333		
Row 4	4	219	54.75	0.25		
Row 5	4	219	54.75	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.264706	0.896043	3.055568
Within Groups	4.25	15	0.283333			
Total	4.55	19				

Table A-201: Co-Header Length vs. Maximum Sync Pulse Width ANOVA

	Max. Sync Pulse Width (us)					
CoHeader Length (ms)	1	2	3	4		
90	57	56	56	57		
95	57	56	57	57		
100	56	56	56	57		
105	56	57	56	56		
110	56	56	56	57		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	226	56.5	0.333333		
Row 2	4	227	56.75	0.25		
Row 3	4	225	56.25	0.25		
Row 4	4	225	56.25	0.25		
Row 5	4	225	56.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.8	4	0.2	0.75	0.573222	3.055568
Within Groups	4	15	0.266667			
Total	4.8	19				

Table A-202: Co-Header Length vs. Minimum Sync Pulse Width ANOVA

	Min. Sync Pulse Width (us)					
CoHeader Length (ms)	1	2	3	4		
90	52	52	51	51		
95	51	51	51	51		
100	52	51	51	51		
105	52	51	51	51		
110	52	52	51	51		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	206	51.5	0.333333		
Row 2	4	204	51	0		
Row 3	4	205	51.25	0.25		
Row 4	4	205	51.25	0.25		
Row 5	4	206	51.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.7	4	0.175	0.75	0.573222	3.055568
Within Groups	3.5	15	0.233333			
Total	4.2	19				

Table A-203: Co-Header Length vs. Maximum Data Pulse Width ANOVA

	Max. Data Width (us)					
CoHeader Length (ms)	1	2	3	4		
90	39	40	40	39		
95	40	40	40	40		
100	39	39	40	39		
105	39	39	40	40		
110	39	40	40	39		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	158	39.5	0.333333		
Row 2	4	160	40	0		
Row 3	4	157	39.25	0.25		
Row 4	4	158	39.5	0.333333		
Row 5	4	158	39.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.2	4	0.3	1.2	0.351289	3.055568
Within Groups	3.75	15	0.25			
Total	4.95	19				

Table A-204: Co-Header Length vs. Minimum Data Pulse Width ANOVA

	Min. data Width (us)					
CoHeader Length (ms)	1	2	3	4		
90	30	30	30	31		
95	30	30	30	30		
100	31	30	30	30		
105	30	30	30	30		
110	31	30	30	30		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	121	30.25	0.25		
Row 2	4	120	30	0		
Row 3	4	121	30.25	0.25		
Row 4	4	120	30	0		
Row 5	4	121	30.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.5	0.736239	3.055568
Within Groups	2.25	15	0.15			
Total	2.55	19				

Table A-205: Co-Header Length vs. Max. Time between Wakeup & Command ANOVA

	Max. Time bet Wakeup & Command					
CoHeader Length (ms)	1	2	3	4		
90	29	29	29	29		
95	28	29	29	28		
100	29	29	28	28		
105	28	29	28	28		
110	29	29	29	29		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	116	29	0		
Row 2	4	114	28.5	0.333333		
Row 3	4	114	28.5	0.333333		
Row 4	4	113	28.25	0.25		
Row 5	4	116	29	0		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.8	4	0.45	2.454545	0.090861	3.055568
Within Groups	2.75	15	0.183333			
Total	4.55	19				

Table A-206: Co-Header Length vs. Min. Time between Wakeup & Command ANOVA

	Min. Time bet Wakeup & Command (us)			
CoHeader Length (ms)	1	2	3	4
90	1	1	1	1
95	1	1	1	1
100	1	1	1	1
105	1	1	1	1
110	1	1	1	1

Table A-207: Co-Header Length Width vs. Tag Awake Time ANOVA

	Tag Awake Time (sec)					
CoHeader Length (ms)	1	2	3	4		
90	29	29	29	28		
95	29	28	29	28		
100	29	29	29	29		
105	29	28	29	29		
110	29	28	29	28		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	115	28.75	0.25		
Row 2	4	114	28.5	0.333333		
Row 3	4	116	29	0		
Row 4	4	115	28.75	0.25		
Row 5	4	114	28.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.7	4	0.175	0.75	0.573222	3.055568
Within Groups	3.5	15	0.233333			
Total	4.2	19				

Table A-208: Co-Header Length vs. Minimum Number of Preambles ANOVA

	Min. No. of Preambles					
CoHeader Length (ms)	1	2	3	4		
90	9	8	8	10		
95	8	9	9	8		
100	9	8	9	8		
105	8	9	9	9		
110	8	9	9	9		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	35	8.75	0.916667		
Row 2	4	34	8.5	0.333333		
Row 3	4	34	8.5	0.333333		
Row 4	4	35	8.75	0.25		
Row 5	4	35	8.75	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.18	0.945217	3.055568
Within Groups	6.25	15	0.416667			
Total	6.55	19				

A.13 TIME BETWEEN WAKEUP & CO-HEADER VS.

The ANOVA tables of Time between Wakeup & Co-Header vs.

1. Carrier Frequency
2. End Pulse Width
3. Initialization Length
4. Termination Length
5. Wakeup Length
6. Co-Header Length
7. Transition Time

are not included in this document as the variation in output for the mentioned factors is zero without any approximation.

Table A-209: Time between Wakeup & Co-Header vs. Maximum FSK Deviation ANOVA

	Max. FSK (kHz)					
Time bet Wakeup & CoHeader (us)	1	2	3	4		
0	85	80	85	80		
200	80	85	80	80		
400	80	85	85	80		
600	80	85	85	80		
800	80	85	80	80		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	330	82.5	8.333333		
Row 2	4	325	81.25	6.25		
Row 3	4	330	82.5	8.333333		
Row 4	4	330	82.5	8.333333		
Row 5	4	325	81.25	6.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7.5	4	1.875	0.25	0.905175	3.055568
Within Groups	112.5	15	7.5			
Total	120	19				

Table A-210: Time between Wakeup & Co-Header vs. Minimum FSK Deviation ANOVA

	Min. FSK (kHz)					
Time bet Wakeup & CoHeader (us)	1	2	3	4		
0	25	20	20	20		
200	20	20	20	20		
400	25	20	20	25		
600	20	20	20	20		
800	25	20	20	20		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	85	21.25	6.25		
Row 2	4	80	20	0		
Row 3	4	90	22.5	8.333333		
Row 4	4	80	20	0		
Row 5	4	85	21.25	6.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	17.5	4	4.375	1.05	0.414603	3.055568
Within Groups	62.5	15	4.166667			
Total	80	19				

Table A-211: Time between Wakeup & Co-Header vs. Max. Wakeup PW ANOVA

	Max. Wakeup Pulse Width (us)					
Time bet Wakeup & CoHeader (us)	1	2	3	4		
0	19	18	18	19		
200	19	19	19	18		
400	18	19	18	19		
600	19	18	19	19		
800	18	19	18	19		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	74	18.5	0.333333		
Row 2	4	75	18.75	0.25		
Row 3	4	74	18.5	0.333333		
Row 4	4	75	18.75	0.25		
Row 5	4	74	18.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.25	0.905175	3.055568
Within Groups	4.5	15	0.3			
Total	4.8	19				

Table A-212: Time between Wakeup & Co-Header vs. Min. Wakeup PW ANOVA

	Min. Wakeup Pulse Width (us)					
Time bet Wakeup & CoHeader (us)	1	2	3	4		
0	14	15	15	14		
200	14	14	14	15		
400	14	15	14	15		
600	14	14	14	15		
800	14	15	14	15		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	58	14.5	0.333333		
Row 2	4	57	14.25	0.25		
Row 3	4	58	14.5	0.333333		
Row 4	4	57	14.25	0.25		
Row 5	4	58	14.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.25	0.905175	3.055568
Within Groups	4.5	15	0.3			
Total	4.8	19				

Table A-213: Time between Wakeup & Co-Header vs. Max. Co-Header PW ANOVA

	Max. CoHeader Pulse Width (us)					
Time bet Wakeup & CoHeader (us)	1	2	3	4		
0	55	56	55	55		
200	56	56	55	55		
400	55	55	56	56		
600	55	55	56	56		
800	55	56	55	55		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	221	55.25	0.25		
Row 2	4	222	55.5	0.333333		
Row 3	4	222	55.5	0.333333		
Row 4	4	222	55.5	0.333333		
Row 5	4	221	55.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.25	0.905175	3.055568
Within Groups	4.5	15	0.3			
Total	4.8	19				

Table A-214: Time between Wakeup & Co-Header vs. Min. Co-Header PW ANOVA

	Min. CoHeader Pulse Width (us)					
Time bet Wakeup & CoHeader (us)	1	2	3	4		
0	48	47	48	47		
200	47	48	47	48		
400	48	47	47	47		
600	47	48	47	48		
800	48	47	47	47		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	190	47.5	0.333333		
Row 2	4	190	47.5	0.333333		
Row 3	4	189	47.25	0.25		
Row 4	4	190	47.5	0.333333		
Row 5	4	189	47.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.25	0.905175	3.055568
Within Groups	4.5	15	0.3			
Total	4.8	19				

Table A-215: Time between Wakeup & Co-Header vs. Max. Preamble PW ANOVA

	Max. Preamble Pulse Width (us)					
Time bet Wakeup & CoHeader (us)	1	2	3	4		
0	67	66	66	67		
200	66	66	66	67		
400	67	66	66	66		
600	66	67	66	66		
800	66	66	66	67		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	266	66.5	0.333333		
Row 2	4	265	66.25	0.25		
Row 3	4	265	66.25	0.25		
Row 4	4	265	66.25	0.25		
Row 5	4	265	66.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.2	4	0.05	0.1875	0.941252	3.055568
Within Groups	4	15	0.266667			
Total	4.2	19				

Table A-216: Time between Wakeup & Co-Header vs. Min. Preamble PW ANOVA

	Min. Preamble Pulse Width (us)					
Time bet Wakeup & CoHeader (us)	1	2	3	4		
0	54	55	55	55		
200	55	54	55	54		
400	54	55	54	55		
600	54	55	55	55		
800	54	55	55	55		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	219	54.75	0.25		
Row 2	4	218	54.5	0.333333		
Row 3	4	218	54.5	0.333333		
Row 4	4	219	54.75	0.25		
Row 5	4	219	54.75	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.264706	0.896043	3.055568
Within Groups	4.25	15	0.283333			
Total	4.55	19				

Table A-217: Time between Wakeup & Co-Header vs. Max. Sync PW ANOVA

	Max. Sync Pulse Width (us)					
Time bet Wakeup & CoHeader (us)	1	2	3	4		
0	57	56	56	57		
200	57	56	57	57		
400	56	56	56	57		
600	56	57	56	56		
800	56	56	56	57		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	226	56.5	0.333333		
Row 2	4	227	56.75	0.25		
Row 3	4	225	56.25	0.25		
Row 4	4	225	56.25	0.25		
Row 5	4	225	56.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.8	4	0.2	0.75	0.573222	3.055568
Within Groups	4	15	0.266667			
Total	4.8	19				

Table A-218: Time between Wakeup & Co-Header vs. Min. Sync PW ANOVA

	Min. Sync Pulse Width (us)					
Time bet Wakeup & CoHeader (us)	1	2	3	4		
0	52	52	51	51		
200	51	51	51	51		
400	52	51	51	51		
600	52	51	51	51		
800	52	52	51	51		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	206	51.5	0.333333		
Row 2	4	204	51	0		
Row 3	4	205	51.25	0.25		
Row 4	4	205	51.25	0.25		
Row 5	4	206	51.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.7	4	0.175	0.75	0.573222	3.055568
Within Groups	3.5	15	0.233333			
Total	4.2	19				

Table A-219: Time between Wakeup & Co-Header vs. Max. Data PW ANOVA

	Max. Data Width (us)					
Time bet Wakeup & CoHeader (us)	1	2	3	4		
0	39	40	40	39		
200	40	40	40	40		
400	39	39	40	39		
600	39	39	40	40		
800	39	40	40	39		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	158	39.5	0.333333		
Row 2	4	160	40	0		
Row 3	4	157	39.25	0.25		
Row 4	4	158	39.5	0.333333		
Row 5	4	158	39.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.2	4	0.3	1.2	0.351289	3.055568
Within Groups	3.75	15	0.25			
Total	4.95	19				

Table A-220: Time between Wakeup & Co-Header vs. Min. Data PW ANOVA

	Min. data Width (us)					
Time bet Wakeup & CoHeader (us)	1	2	3	4		
0	30	30	30	31		
200	30	30	30	30		
400	31	30	30	30		
600	30	30	30	30		
800	31	30	30	30		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	121	30.25	0.25		
Row 2	4	120	30	0		
Row 3	4	121	30.25	0.25		
Row 4	4	120	30	0		
Row 5	4	121	30.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.5	0.736239	3.055568
Within Groups	2.25	15	0.15			
Total	2.55	19				

Table A-221: Time bet Wakeup & CoHeader vs. Max. Time bet Wakeup & Cmd ANOVA

	Max. Time bet Wakeup & Command					
Time bet Wakeup & CoHeader (us)	1	2	3	4		
0	29	29	29	29		
200	28	29	29	28		
400	29	29	28	28		
600	28	29	28	28		
800	29	29	29	29		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	116	29	0		
Row 2	4	114	28.5	0.333333		
Row 3	4	114	28.5	0.333333		
Row 4	4	113	28.25	0.25		
Row 5	4	116	29	0		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.8	4	0.45	2.454545	0.090861	3.055568
Within Groups	2.75	15	0.183333			
Total	4.55	19				

Table A-222: Time bet Wakeup & CoHeader vs. Min. Time bet Wakeup & Cmd ANOVA

	Min. Time bet Wakeup & Command (us)			
Time bet Wakeup & CoHeader (us)	1	2	3	4
0	1	1	1	1
200	1	1	1	1
400	1	1	1	1
600	1	1	1	1
800	1	1	1	1

Table A-223: Time between Wakeup & Co-Header vs. Tag Awake Time ANOVA

	Tag Awake Time (sec)					
Time bet Wakeup & CoHeader (us)	1	2	3	4		
0	29	29	29	28		
200	29	28	29	28		
400	29	29	29	29		
600	29	28	29	29		
800	29	28	29	28		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	115	28.75	0.25		
Row 2	4	114	28.5	0.333333		
Row 3	4	116	29	0		
Row 4	4	115	28.75	0.25		
Row 5	4	114	28.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.7	4	0.175	0.75	0.573222	3.055568
Within Groups	3.5	15	0.233333			
Total	4.2	19				

Table A-224: Time bet Wakeup & CoHeader vs. Min. Number of Preambles ANOVA

	Min. No. of Preambles					
Time bet Wakeup & CoHeader (us)	1	2	3	4		
0	9	8	8	10		
200	8	9	9	8		
400	9	8	9	8		
600	8	9	9	9		
800	8	9	9	9		
SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Row 1	4	35	8.75	0.916667		
Row 2	4	34	8.5	0.333333		
Row 3	4	34	8.5	0.333333		
Row 4	4	35	8.75	0.25		
Row 5	4	35	8.75	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.18	0.945217	3.055568
Within Groups	6.25	15	0.416667			
Total	6.55	19				

A.14 TIME BETWEEN WAKEUP & COMMAND VS.

The ANOVA tables of Time between Wakeup & Co-Header vs.

1. Carrier Frequency
2. End Pulse Width
3. Initialization Length
4. Termination Length
5. Wakeup Length
6. Co-Header Length
7. Time between Wakeup & Co-Header
8. Transition Time

are not included in this document as the variation in output for the mentioned factors is zero without any approximation.

Table A-225: Time between Wakeup & Command vs. Maximum FSK Deviation ANOVA

	Max. FSK (kHz)			
Time bet Wakeup & Command (sec)	1	2	3	4
1u	85	80	85	80
1	80	85	80	80
2	80	85	85	80
3	80	85	85	80
4	80	85	80	80
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	330	82.5	8.333333
Row 2	4	325	81.25	6.25
Row 3	4	330	82.5	8.333333
Row 4	4	330	82.5	8.333333
Row 5	4	325	81.25	6.25

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	7.5	4	1.875	0.25	0.905175	3.055568
Within Groups	112.5	15	7.5			
Total	120	19				

Table A-226: Time between Wakeup & Command vs. Minimum FSK Deviation ANOVA

	Min. FSK (kHz)			
Time bet Wakeup & Command (sec)	1	2	3	4
1u	25	20	20	20
1	20	20	20	20
2	25	20	20	25
3	20	20	20	20
4	25	20	20	20
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	85	21.25	6.25
Row 2	4	80	20	0
Row 3	4	90	22.5	8.333333
Row 4	4	80	20	0
Row 5	4	85	21.25	6.25

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	17.5	4	4.375	1.05	0.414603	3.055568
Within Groups	62.5	15	4.166667			
Total	80	19				

Table A-227: Time between Wakeup & Cmd vs. Max. Wakeup PW ANOVA

	Max. Wakeup Pulse Width (us)			
Time bet Wakeup & Command (sec)	1	2	3	4
1u	19	18	18	19
1	19	19	19	18
2	18	19	18	19
3	19	18	19	19
4	18	19	18	19
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	74	18.5	0.333333
Row 2	4	75	18.75	0.25
Row 3	4	74	18.5	0.333333
Row 4	4	75	18.75	0.25
Row 5	4	74	18.5	0.333333

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.25	0.905175	3.055568
Within Groups	4.5	15	0.3			
Total	4.8	19				

Table A-228: Time between Wakeup & Cmd vs. Min. Wakeup PW ANOVA

	Min. CoHeader Pulse Width (us)			
Time bet Wakeup & Command (sec)	1	2	3	4
1u	14	15	15	14
1	14	14	14	15
2	14	15	14	15
3	14	14	14	15
4	14	15	14	15
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	58	14.5	0.333333
Row 2	4	57	14.25	0.25
Row 3	4	58	14.5	0.333333
Row 4	4	57	14.25	0.25
Row 5	4	58	14.5	0.333333

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.25	0.905175	3.055568
Within Groups	4.5	15	0.3			
Total	4.8	19				

Table A-229: Time between Wakeup & Cmd vs. Max. Co-Header PW ANOVA

	Max. CoHeader Pulse Width (us)			
Time bet Wakeup & Command (sec)	1	2	3	4
1u	55	56	55	55
1	56	56	55	55
2	55	55	56	56
3	55	55	56	56
4	55	56	55	55
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	221	55.25	0.25
Row 2	4	222	55.5	0.333333
Row 3	4	222	55.5	0.333333
Row 4	4	222	55.5	0.333333
Row 5	4	221	55.25	0.25

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.25	0.905175	3.055568
Within Groups	4.5	15	0.3			
Total	4.8	19				

Table A-230: Time between Wakeup & Cmd vs. Min. Co-Header PW ANOVA

	Min. CoHeader Pulse Width (us)			
Time bet Wakeup & Command (sec)	1	2	3	4
1u	48	47	48	47
1	47	48	47	48
2	48	47	47	47
3	47	48	47	48
4	48	47	47	47
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	190	47.5	0.333333
Row 2	4	190	47.5	0.333333
Row 3	4	189	47.25	0.25
Row 4	4	190	47.5	0.333333
Row 5	4	189	47.25	0.25

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.25	0.905175	3.055568
Within Groups	4.5	15	0.3			
Total	4.8	19				

Table A-231: Time between Wakeup & Cmd vs. Max. Preamble PW ANOVA

	Max. Preamble Pulse Width (us)					
Time bet Wakeup & Command (sec)	1	2	3	4		
1u	67	66	66	67		
1	66	66	66	67		
2	67	66	66	66		
3	66	67	66	66		
4	66	66	66	67		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	266	66.5	0.333333		
Row 2	4	265	66.25	0.25		
Row 3	4	265	66.25	0.25		
Row 4	4	265	66.25	0.25		
Row 5	4	265	66.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.2	4	0.05	0.1875	0.941252	3.055568
Within Groups	4	15	0.266667			
Total	4.2	19				

Table A-232: Time between Wakeup & Cmd vs. Min. Preamble PW ANOVA

	Min. Preamble Pulse Width (us)					
Time bet Wakeup & Command (sec)	1	2	3	4		
1u	54	55	55	55		
1	55	54	55	54		
2	54	55	54	55		
3	54	55	55	55		
4	54	55	55	55		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	219	54.75	0.25		
Row 2	4	218	54.5	0.333333		
Row 3	4	218	54.5	0.333333		
Row 4	4	219	54.75	0.25		
Row 5	4	219	54.75	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.264706	0.896043	3.055568
Within Groups	4.25	15	0.283333			
Total	4.55	19				

Table A-233: Time between Wakeup & Cmd vs. Max. Sync PW ANOVA

	Max. Sync Pulse Width (us)					
Time bet Wakeup & Command (sec)	1	2	3	4		
1u	57	56	56	57		
1	57	56	57	57		
2	56	56	56	57		
3	56	57	56	56		
4	56	56	56	57		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	226	56.5	0.333333		
Row 2	4	227	56.75	0.25		
Row 3	4	225	56.25	0.25		
Row 4	4	225	56.25	0.25		
Row 5	4	225	56.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.8	4	0.2	0.75	0.573222	3.055568
Within Groups	4	15	0.266667			
Total	4.8	19				

Table A-234: Time between Wakeup & Cmd vs. Min. Sync PW ANOVA

	Min. Sync Pulse Width (us)					
Time bet Wakeup & Command (sec)	1	2	3	4		
1u	52	52	51	51		
1	51	51	51	51		
2	52	51	51	51		
3	52	51	51	51		
4	52	52	51	51		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	206	51.5	0.333333		
Row 2	4	204	51	0		
Row 3	4	205	51.25	0.25		
Row 4	4	205	51.25	0.25		
Row 5	4	206	51.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.7	4	0.175	0.75	0.573222	3.055568
Within Groups	3.5	15	0.233333			
Total	4.2	19				

Table A-235: Time between Wakeup & Cmd vs. Max. Data PW ANOVA

	Max. Data Width (us)					
Time bet Wakeup & Command (sec)	1	2	3	4		
1u	39	40	40	39		
1	40	40	40	40		
2	39	39	40	39		
3	39	39	40	40		
4	39	40	40	39		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	158	39.5	0.333333		
Row 2	4	160	40	0		
Row 3	4	157	39.25	0.25		
Row 4	4	158	39.5	0.333333		
Row 5	4	158	39.5	0.333333		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1.2	4	0.3	1.2	0.351289	3.055568
Within Groups	3.75	15	0.25			
Total	4.95	19				

Table A-236: Time between Wakeup & Command vs. Minimum Data PW ANOVA

	Min. data Width (us)					
Time bet Wakeup & Command (sec)	1	2	3	4		
1u	30	30	30	31		
1	30	30	30	30		
2	31	30	30	30		
3	30	30	30	30		
4	31	30	30	30		
SUMMARY						
Groups	Count	Sum	Average	Variance		
Row 1	4	121	30.25	0.25		
Row 2	4	120	30	0		
Row 3	4	121	30.25	0.25		
Row 4	4	120	30	0		
Row 5	4	121	30.25	0.25		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.5	0.736239	3.055568
Within Groups	2.25	15	0.15			
Total	2.55	19				

Table A-237: Time between Wakeup & Command vs. Tag Awake Time ANOVA

	Tag Awake Time (sec)			
Time bet Wakeup & Command (sec)	1	2	3	4
1u	29	29	29	28
1	29	28	29	28
2	29	29	29	29
3	29	28	29	29
4	29	28	29	28
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	115	28.75	0.25
Row 2	4	114	28.5	0.333333
Row 3	4	116	29	0
Row 4	4	115	28.75	0.25
Row 5	4	114	28.5	0.333333

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.7	4	0.175	0.75	0.573222	3.055568
Within Groups	3.5	15	0.233333			
Total	4.2	19				

Table A-238: Time bet Wakeup & Cmd vs. Min. Number of Preambles ANOVA

	Min. No. of Preambles			
Time bet Wakeup & Command (sec)	1	2	3	4
1u	9	8	8	10
1	8	9	9	8
2	9	8	9	8
3	8	9	9	9
4	8	9	9	9
SUMMARY				
Groups	Count	Sum	Average	Variance
Row 1	4	35	8.75	0.916667
Row 2	4	34	8.5	0.333333
Row 3	4	34	8.5	0.333333
Row 4	4	35	8.75	0.25
Row 5	4	35	8.75	0.25

ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.3	4	0.075	0.18	0.945217	3.055568
Within Groups	6.25	15	0.416667			
Total	6.55	19				

APPENDIX B

INTEROPERABILITY TEST RESULT OF A COMMERCIAL TAG

INTEROPERABILITY TEST SUITE

Test started at 6:29:59.371 PM 6/29/2009

GOLD Command Sent

Tag Manufacturer ID = [redacted] (Not disclosed under NDA)

Tag Serial Number = [redacted] (Not disclosed under NDA)

Minimum 20 Preambles = Pass

Transition Time of 0 - 2.4us = Pass

Transition Time of 2.4 - 3.1us = Pass

Transition Time of 3.1 - 3.9us = Pass

Wakeup Length of 3.018176 = Pass

Wakeup Length of 2.572736 = Pass

Wakeup Length of 2.349984 = Pass

Wakeup Length of 3.909088 = Pass

Wakeup Length of 3.686368 = Pass

Wakeup Length of 4.800000 = Pass

Wakeup Length of 3.240896 = Pass

Wakeup Length of 3.463648 = Pass

Wakeup Length of 4.577280 = Pass

Wakeup Length of 2.795456 = Pass

Wakeup Length of 4.354560 = Pass

Wakeup Length of 4.131808 = Pass

CoHeader Length of 102.000000m = Pass

CoHeader Length of 101.300000m = Pass

CoHeader Length of 99.100000m = Pass

CoHeader Length of 99.800000m = Pass

CoHeader Length of 98.700000m = Pass

CoHeader Length of 98.400000m = Pass

CoHeader Length of 101.600000m = Pass

CoHeader Length of 100.500000m = Pass

CoHeader Length of 100.900000m = Pass

CoHeader Length of 98.000000m = Pass

CoHeader Length of 99.500000m = Pass

CoHeader Length of 100.200000m = Pass

Time Between Wakeup & CoHeader of 218.181800m = Pass

Time Between Wakeup & CoHeader of 2.181818 = Pass

Time Between Wakeup & CoHeader of 327.272800m = Pass

Time Between Wakeup & CoHeader of 2.290909 = Pass

Time Between Wakeup & CoHeader of 545.454600m = Pass

Time Between Wakeup & CoHeader of 2.400000 = Pass

Time Between Wakeup & CoHeader of 1.200000 = Pass

Time Between Wakeup & CoHeader of 763.636400m = Pass

Time Between Wakeup & CoHeader of 436.363600m = Pass

Time Between Wakeup & CoHeader of 1.636364 = Pass

Time Between Wakeup & CoHeader of 1.745455 = Pass

Time Between Wakeup & CoHeader of 1.963636 = Pass

Time Between Wakeup & CoHeader of 1.309091 = Pass

Time Between Wakeup & CoHeader of 1.854545 = Pass

Time Between Wakeup & CoHeader of 2.072727 = Pass

Time Between Wakeup & CoHeader of 109.091000m = Pass

Time Between Wakeup & CoHeader of 981.818200m = Pass

Time Between Wakeup & CoHeader of 1.090909 = Pass

Time Between Wakeup & CoHeader of 0.000000 = Pass

Time Between Wakeup & CoHeader of 1.418182 = Pass

Time Between Wakeup & CoHeader of 654.545400m = Pass

Time Between Wakeup & CoHeader of 1.527273 = Pass

Time Between Wakeup & CoHeader of 872.727200m = Pass

Time Between CoHeader & Command of 13.000000 = Pass

Time Between CoHeader & Command of 29.000000 = Pass

Time Between CoHeader & Command of 3.000000 = Pass

Time Between CoHeader & Command of 4.000000 = Pass

Time Between CoHeader & Command of 21.000000 = Pass

Time Between CoHeader & Command of 18.000000 = Pass

Time Between CoHeader & Command of 7.000000 = Pass

Time Between CoHeader & Command of 20.000000 = Pass

Time Between CoHeader & Command of 9.000000 = Pass

Time Between CoHeader & Command of 25.000000 = Pass

Time Between CoHeader & Command of 1.000000 = Pass

Time Between CoHeader & Command of 14.000000 = Pass

Time Between CoHeader & Command of 11.000000 = Pass

Time Between CoHeader & Command of 22.000000 = Pass

Time Between CoHeader & Command of 5.000000 = Pass

Time Between CoHeader & Command of 0.000000 = Pass

Time Between CoHeader & Command of 8.000000 = Pass

Time Between CoHeader & Command of 12.000000 = Pass

Time Between CoHeader & Command of 17.000000 = Pass

Time Between CoHeader & Command of 26.000000 = Pass

Time Between CoHeader & Command of 28.000000 = Pass

Time Between CoHeader & Command of 24.000000 = Pass

Time Between CoHeader & Command of 16.000000 = Pass

Tag Awake Time of 29.000000 Result = Pass

Wakeup Pulse Width of 32.400000u = Pass

Wakeup Pulse Width of 31.200000u = Pass

Wakeup Pulse Width of 32.800000u = Pass

Wakeup Pulse Width of 31.600000u = Pass

CoHeader Pulse Width of 101.600000u = Pass

CoHeader Pulse Width of 98.800000u = Pass

CoHeader Pulse Width of 101.200000u = Pass

CoHeader Pulse Width of 98.400000u = Pass

CoHeader Pulse Width of 98.000000u = Pass

CoHeader Pulse Width of 99.200000u = Pass

CoHeader Pulse Width of 100.400000u = Pass

CoHeader Pulse Width of 99.600000u = Pass

CoHeader Pulse Width of 100.800000u = Pass

CoHeader Pulse Width of 102.000000u = Pass

Command Data 0x 40 04 0C AA AA 1F 00 08 1F 00 = Pass

Tag Reply Data 0x 40 00 08 1C AA AA [redacted] 1F 00 00 [redacted] (Not disclosed under NDA)

Preamble Pulse Width of 59.020000u = Pass

Preamble Pulse Width of 59.900000u = Pass

Preamble Pulse Width of 60.440000u = Pass

Preamble Pulse Width of 60.320000u = Pass

Preamble Pulse Width of 60.100000u = Pass

Preamble Pulse Width of 59.120000u = Pass

Preamble Pulse Width of 60.220000u = Pass

Preamble Pulse Width of 60.660000u = Pass

Preamble Pulse Width of 59.780000u = Pass

Preamble Pulse Width of 61.100000u = Pass

Preamble Pulse Width of 58.800000u = Pass

Preamble Pulse Width of 59.560000u = Pass

Preamble Pulse Width of 60.760000u = Pass

Preamble Pulse Width of 60.540000u = Pass

Preamble Pulse Width of 61.200000u = Pass

Preamble Pulse Width of 59.460000u = Pass

Preamble Pulse Width of 60.980000u = Pass

Preamble Pulse Width of 58.900000u = Pass

Preamble Pulse Width of 60.880000u = Pass

Preamble Pulse Width of 59.340000u = Pass

Preamble Pulse Width of 60.000000u = Pass

Preamble Pulse Width of 59.240000u = Pass

Preamble Pulse Width of 59.680000u = Pass

Sync Pulse Width of 106.360000u = Pass

Sync Pulse Width of 109.820000u = Pass

Sync Pulse Width of 107.100000u = Pass

Sync Pulse Width of 109.280000u = Pass

Sync Pulse Width of 107.820000u = Pass

Sync Pulse Width of 107.460000u = Pass

Sync Pulse Width of 108.900000u = Pass

Sync Pulse Width of 107.280000u = Pass

Sync Pulse Width of 110.000000u = Pass

Sync Pulse Width of 108.180000u = Pass

Sync Pulse Width of 108.720000u = Pass

Sync Pulse Width of 106.900000u = Pass

Sync Pulse Width of 106.000000u = Pass

Sync Pulse Width of 107.640000u = Pass

Sync Pulse Width of 106.540000u = Pass

Sync Pulse Width of 108.540000u = Pass

Sync Pulse Width of 109.460000u = Pass

Sync Pulse Width of 108.000000u = Pass

Sync Pulse Width of 109.640000u = Pass

Sync Pulse Width of 108.360000u = Pass

Sync Pulse Width of 106.180000u = Pass

Sync Pulse Width of 109.100000u = Pass

Sync Pulse Width of 106.720000u = Pass
Data Pulse Width of 36.180000u = Pass
Data Pulse Width of 36.440000u = Pass
Data Pulse Width of 35.960000u = Pass
Data Pulse Width of 36.720000u = Pass
Data Pulse Width of 36.680000u = Pass
Data Pulse Width of 36.600000u = Pass
Data Pulse Width of 36.200000u = Pass
Data Pulse Width of 35.420000u = Pass
Data Pulse Width of 35.560000u = Pass
Data Pulse Width of 35.660000u = Pass
Data Pulse Width of 35.860000u = Pass
Data Pulse Width of 36.580000u = Pass
Data Pulse Width of 36.500000u = Pass
Data Pulse Width of 35.520000u = Pass
Data Pulse Width of 35.300000u = Pass
Data Pulse Width of 35.320000u = Pass
Data Pulse Width of 36.300000u = Pass
Data Pulse Width of 36.620000u = Pass
Data Pulse Width of 36.320000u = Pass
Data Pulse Width of 35.280000u = Pass
Data Pulse Width of 35.620000u = Pass
Data Pulse Width of 36.540000u = Pass
Data Pulse Width of 35.880000u = Pass
Data Pulse Width of 36.280000u = Pass
Data Pulse Width of 36.100000u = Pass
Data Pulse Width of 36.080000u = Pass
Data Pulse Width of 36.480000u = Pass
Data Pulse Width of 35.800000u = Pass
Data Pulse Width of 35.360000u = Pass
Data Pulse Width of 36.380000u = Pass

Data Pulse Width of 35.980000u = Pass

Data Pulse Width of 35.380000u = Pass

Data Pulse Width of 36.520000u = Pass

Data Pulse Width of 36.140000u = Pass

Data Pulse Width of 36.040000u = Pass

Data Pulse Width of 35.400000u = Pass

Data Pulse Width of 35.680000u = Pass

Data Pulse Width of 36.240000u = Pass

Data Pulse Width of 35.700000u = Pass

Data Pulse Width of 36.700000u = Pass

Data Pulse Width of 35.500000u = Pass

Data Pulse Width of 36.220000u = Pass

Data Pulse Width of 36.400000u = Pass

Data Pulse Width of 35.460000u = Pass

Data Pulse Width of 35.600000u = Pass

Data Pulse Width of 35.920000u = Pass

Data Pulse Width of 35.900000u = Pass

Data Pulse Width of 36.340000u = Pass

Data Pulse Width of 36.420000u = Pass

Data Pulse Width of 35.720000u = Pass

Data Pulse Width of 35.580000u = Pass

Data Pulse Width of 35.760000u = Pass

Data Pulse Width of 36.000000u = Pass

Data Pulse Width of 35.780000u = Pass

Data Pulse Width of 36.020000u = Pass

Data Pulse Width of 35.480000u = Pass

Data Pulse Width of 36.120000u = Pass

Data Pulse Width of 35.820000u = Pass

Data Pulse Width of 36.640000u = Pass

End Pulse Width of 35.550000u = Pass

End Pulse Width of 35.640000u = Pass

End Pulse Width of 35.730000u = Pass

End Pulse Width of 36.720000u = Pass

End Pulse Width of 35.460000u = Pass

End Pulse Width of 36.090000u = Pass

End Pulse Width of 36.270000u = Pass

End Pulse Width of 36.630000u = Pass

End Pulse Width of 35.910000u = Pass

End Pulse Width of 35.820000u = Pass

End Pulse Width of 36.540000u = Pass

End Pulse Width of 36.360000u = Pass

End Pulse Width of 35.280000u = Pass

End Pulse Width of 36.000000u = Pass

End Pulse Width of 36.450000u = Pass

End Pulse Width of 36.180000u = Pass

End Pulse Width of 35.370000u = Pass

Initialization Pulse Width of 15.000000u = Pass

Termination Pulse Width of 15.000000u = Pass

Carrier of 433.922000M & FSK of 57.000000k = Pass

Carrier of 433.922000M & FSK of 48.000000k = Pass

Carrier of 433.922000M & FSK of 55.000000k = Pass

Carrier of 433.922000M & FSK of 47.000000k = Pass

Carrier of 433.922000M & FSK of 42.000000k = Pass

Carrier of 433.922000M & FSK of 59.000000k = Pass

Carrier of 433.922000M & FSK of 56.000000k = Pass

Carrier of 433.922000M & FSK of 44.000000k = Pass

Carrier of 433.922000M & FSK of 58.000000k = Pass

Carrier of 433.922000M & FSK of 41.000000k = Pass

Carrier of 433.922000M & FSK of 49.000000k = Pass

Carrier of 433.922000M & FSK of 40.000000k = Pass

Carrier of 433.922000M & FSK of 53.000000k = Pass

Carrier of 433.922000M & FSK of 45.000000k = Pass

Carrier of 433.922000M & FSK of 54.000000k = Pass

Carrier of 433.922000M & FSK of 43.000000k = Pass

Carrier of 433.922000M & FSK of 60.000000k = Pass

Carrier of 433.922000M & FSK of 51.000000k = Pass

Carrier of 433.922000M & FSK of 52.000000k = Pass

Carrier of 433.922000M & FSK of 46.000000k = Pass

Carrier of 433.928000M & FSK of 57.000000k = Pass

Carrier of 433.928000M & FSK of 48.000000k = Pass

Carrier of 433.928000M & FSK of 55.000000k = Pass

Carrier of 433.928000M & FSK of 47.000000k = Pass

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Carrier of 433.928000M & FSK of 58.000000k = Pass

Carrier of 433.928000M & FSK of 41.000000k = Pass

Carrier of 433.928000M & FSK of 49.000000k = Pass

Carrier of 433.928000M & FSK of 40.000000k = Pass

Carrier of 433.928000M & FSK of 53.000000k = Pass

Carrier of 433.928000M & FSK of 45.000000k = Pass

Carrier of 433.928000M & FSK of 54.000000k = Pass

Carrier of 433.928000M & FSK of 43.000000k = Pass

Carrier of 433.928000M & FSK of 60.000000k = Pass

Carrier of 433.928000M & FSK of 51.000000k = Pass

Carrier of 433.928000M & FSK of 52.000000k = Pass

Carrier of 433.928000M & FSK of 46.000000k = Pass

Carrier of 433.906000M & FSK of 57.000000k = Pass

Carrier of 433.906000M & FSK of 48.000000k = Pass

Carrier of 433.906000M & FSK of 55.000000k = Pass

Carrier of 433.906000M & FSK of 47.000000k = Pass

Carrier of 433.906000M & FSK of 42.000000k = Pass

Carrier of 433.906000M & FSK of 59.000000k = Pass

Carrier of 433.906000M & FSK of 56.000000k = Pass

Carrier of 433.906000M & FSK of 44.000000k = Pass

Carrier of 433.906000M & FSK of 58.000000k = Pass

Carrier of 433.906000M & FSK of 41.000000k = Pass

Carrier of 433.906000M & FSK of 49.000000k = Pass

Carrier of 433.906000M & FSK of 40.000000k = Pass

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Carrier of 433.906000M & FSK of 52.000000k = Pass

Carrier of 433.906000M & FSK of 46.000000k = Pass

Carrier of 433.911000M & FSK of 57.000000k = Pass

Carrier of 433.911000M & FSK of 48.000000k = Pass

Carrier of 433.911000M & FSK of 55.000000k = Pass

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Carrier of 433.911000M & FSK of 44.000000k = Pass

Carrier of 433.911000M & FSK of 58.000000k = Pass

Carrier of 433.911000M & FSK of 41.000000k = Pass

Carrier of 433.911000M & FSK of 49.000000k = Pass

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Carrier of 433.911000M & FSK of 53.000000k = Pass

Carrier of 433.911000M & FSK of 45.000000k = Pass

Carrier of 433.911000M & FSK of 54.000000k = Pass

Carrier of 433.911000M & FSK of 43.000000k = Pass

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Carrier of 433.911000M & FSK of 51.000000k = Pass
Carrier of 433.911000M & FSK of 52.000000k = Pass
Carrier of 433.911000M & FSK of 46.000000k = Pass
Carrier of 433.917000M & FSK of 57.000000k = Pass
Carrier of 433.917000M & FSK of 48.000000k = Pass
Carrier of 433.917000M & FSK of 55.000000k = Pass
Carrier of 433.917000M & FSK of 47.000000k = Pass
Carrier of 433.917000M & FSK of 42.000000k = Pass
Carrier of 433.917000M & FSK of 59.000000k = Pass
Carrier of 433.917000M & FSK of 56.000000k = Pass
Carrier of 433.917000M & FSK of 44.000000k = Pass
Carrier of 433.917000M & FSK of 58.000000k = Pass
Carrier of 433.917000M & FSK of 41.000000k = Pass
Carrier of 433.917000M & FSK of 49.000000k = Pass
Carrier of 433.917000M & FSK of 40.000000k = Pass
Carrier of 433.917000M & FSK of 53.000000k = Pass
Carrier of 433.917000M & FSK of 45.000000k = Pass
Carrier of 433.917000M & FSK of 54.000000k = Pass
Carrier of 433.917000M & FSK of 43.000000k = Pass
Carrier of 433.917000M & FSK of 60.000000k = Pass
Carrier of 433.917000M & FSK of 51.000000k = Pass
Carrier of 433.917000M & FSK of 52.000000k = Pass
Carrier of 433.917000M & FSK of 46.000000k = Pass
Carrier of 433.933000M & FSK of 57.000000k = Pass
Carrier of 433.933000M & FSK of 48.000000k = Pass
Carrier of 433.933000M & FSK of 55.000000k = Pass
Carrier of 433.933000M & FSK of 47.000000k = Pass
Carrier of 433.933000M & FSK of 42.000000k = Pass
Carrier of 433.933000M & FSK of 59.000000k = Pass
Carrier of 433.933000M & FSK of 56.000000k = Pass

Carrier of 433.933000M & FSK of 44.000000k = Pass
Carrier of 433.933000M & FSK of 58.000000k = Pass
Carrier of 433.933000M & FSK of 41.000000k = Pass
Carrier of 433.933000M & FSK of 49.000000k = Pass
Carrier of 433.933000M & FSK of 40.000000k = Pass
Carrier of 433.933000M & FSK of 53.000000k = Pass
Carrier of 433.933000M & FSK of 45.000000k = Pass
Carrier of 433.933000M & FSK of 54.000000k = Pass
Carrier of 433.933000M & FSK of 43.000000k = Pass
Carrier of 433.933000M & FSK of 60.000000k = Pass
Carrier of 433.933000M & FSK of 51.000000k = Pass
Carrier of 433.933000M & FSK of 52.000000k = Pass
Carrier of 433.933000M & FSK of 46.000000k = Pass

Minimum Number of Preambles: Interoperable. Tag Under Test accepts the Minimum number of Preambles Transmitted

Transition Times: Interoperable. Tag Under Test accepts the Transition Times Transmitted

Wakeup Length: Interoperable. With confidence level of 95 % the error in interoperability property of the factor is < 5 %

CoHeader Length: Interoperable. With confidence level of 95 % the error in interoperability property of the factor is < 5 %

Time bet. Wakeup & CoHeader: Interoperable. With confidence level of 95 % the error in interoperability property of the factor is < 5 %

Time bet. Wakeup & Command: Interoperable. With confidence level of 95 % the error in interoperability property of the factor is < 5 %

Tag Awake Time: Interoperable. With confidence level of 95 % the error in interoperability property of the factor is < 5 %

Wakeup Pulse Width: Interoperable. With confidence level of 95 % the error in interoperability property of the factor is < 40 %

CoHeader Pulse Width: Interoperable. With confidence level of 95 % the error in interoperability property of the factor is < 15 %

Commands Supported: Interoperable. Tag Under Test responds to all Commands Transmitted

Preamble Pulse Width: Interoperable. With confidence level of 95 % the error in interoperability property of the factor is < 5 %

Sync Pulse Width: Interoperable. With confidence level of 95 % the error in interoperability property of the factor is < 5 %

Data Pulse Width: Interoperable. With confidence level of 95 % the error in interoperability property of the factor is < 5 %

End Pulse Width: Interoperable. With confidence level of 95 % the error in interoperability property of the factor is < 5 %

Initialization Pulse: Interoperable. Tag Under Test responds to commands transmitted with the Initialization Pulse

Termination Pulse: Interoperable. Tag Under Test responds to commands transmitted with the Termination Pulse

FSK Deviation: Interoperable. With confidence level of 95 % the error in interoperability property of the factor is < 11 %

Carrier: Interoperable. With confidence level of 95 % the error in interoperability property of the factor is < 5 %

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